15TH ASSEMBLY OF PETROLOGY AND GEOCHEMISTRY

Nagybörzsöny – Banská Štiavnica

2-4 October 2025

"The whispers of rock, stories from the Earth"

Nagybörzsöny

Banská Štiavnica

2025

15th ASSEMBLY of PETROLOGY and GEOCHEMISTRY

BOOK OF ABSTRACTS

15th Assembly of Petrology and Geochemistry, Book of Abstracts

Editors

Attila VIRÁG, Barbara CSERÉP, Kata MOLNÁR, Máté SZEMERÉDI

Scientific Reviewers

Kata MOLNÁR, Máté SZEMERÉDI, Attila VIRÁG

Responsible Publisher

László Kiss
executive director
HUN-REN Research Centre for Astronomy and Earth Sciences
www.csfk.org

ISBN 978-963-8361-64-6

Motto
Anjana Khatwa

Cover Art
The Calvary of Banská Štiavnica (Photo: Jaroslav LEXA)

Conference Organizers

Réka LUKÁCS[1,2] (Head of the Organizing Committee)

Barbara CSERÉP[1,2], György CZUPPON[1], Péter GÁL[1,2], Krisztina HAJDU[1,2], Szabolcs HARANGI[1,2], Máté KARLIK[3], Ivett KOVÁCS[1], Emese OELBERG-PÁNCZÉL[1,2], János SZEPESI[1,4], Máté SZEMEREDI[1,5], Kata TEMOVSKI-MOLNÁR[1,4], Attila VIRÁG[1,2]

Igor BROSKA[6], Milan KOHÚT[6], Samuel RYBÁR[7,8], Katarína ŠARINOVÁ[9]

[1] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group
[2] Department of Petrology & Geochemistry, Institute of Geography and Earth Sciences, Eötvös Loránd University
[3] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research
[4] HUN-REN Geochronology Group, Institute for Nuclear Research (ATOMKI)
[5] Department of Geology, 'Vulcano' Petrology and Geochemistry Research Group, University of Szeged
[6] Earth Science Institute of the Slovak Academy of Sciences
[7] Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University
[8] Department of Geodesy and Mine Surveying, Faculty of Mining and Geology, Technical University of Ostrava
[9] Department of Mineralogy, Petrology and Economic Geology, Faculty of Natural Sciences, Comenius University

The **Assembly of Petrology and Geochemistry** is an official event of the *Subcommittee on Petrology* of the *Committee on Geochemistry, Mineralogy and Petrology* of the *Hungarian Academy of Sciences* and the *Mineralogy, Petrology and Geochemistry Section* of the *Hungarian Geological Society*.

PREFACE

Fifteen years ago, in 2010, we held the very first Petrology and Geochemistry Meeting with a clear vision: to bring together the Hungarian community, to share research, build meaningful professional relationships, and to encourage the next generation of scientists, our students and early-career researchers, to become active members of our scientific field. We believed then, as we do now, that providing a platform for researchers to present their work in their native language is essential for fostering a strong, connected local community.

The 15th Assembly of Petrology and Geochemistry of Hungary, held in collaboration with our esteemed Slovak colleagues, represents a significant milestone in this tradition. This international conference opens new opportunities: to broaden our networks, to build live collaborations across borders, and to strengthen ties with colleagues and young scientists from neighbouring countries.

Our field faces undeniable challenges. Scientific communities are shrinking, student numbers are declining, and the natural sciences are losing visibility in society. Meanwhile, researchers are under increasing pressure from administrative tasks, publication demands, and metrics-driven evaluations. In such an environment, it becomes difficult to find time for deep scientific thinking, for the joy of discovery, and for reflection.

This conference is an opportunity to counteract that trend, to reconnect, to discover each other's work, to explore new directions, and to reinforce our sense of community. The future of our discipline depends on us. None of us can secure it alone, but together we can: by recognizing the value of each other's work, by sharing it beyond our immediate circles, and by ensuring that our science is seen and appreciated, not only locally, but across Europe and beyond.

The Assembly takes place in the picturesque village of Nagybörzsöny, between October 2–4, 2025. Over three days, participants will engage in a rich program: three plenary lectures by renowned experts, 36 oral presentations, and 24 poster presentations, covering a wide spectrum of topics in petrology and geochemistry. We are particularly grateful to our Slovakian colleagues for organizing the field trips, which will lead participants to the Central Slovakian Volcanic Field and the UNESCO World Heritage site of Banská Štiavnica, both outstanding examples of the geological and cultural heritage of the region.

Polymetallic mineralization from Hodruša-Hámre site -Štiavnica stratovolcano, Rozália mine: it contains galena, pyrite, chalcopyrite, sphalerite, quartz, ±barite and carbonates. There may also be microscopic gold. The host rock is andesite and granodiorite (collected by Katarína Šarinová and Samuel Rybár, photo is taken by Samuel Rybár).

We sincerely hope this meeting will serve as a stepping stone for new collaborations, inspire future advances, and strengthen the bonds within our scientific community.

On behalf of the organizing committee, we wish you a productive and enjoyable conference. We extend our deepest thanks to all contributors and sponsors whose support has made this event possible.

Réka Lukács
Head of the Organizing Committee

NAGYBÖRZSÖNY (DEUTSCHPILSEN) IN A NUTSHELL

Lange Thomas Pieter*
HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary
* E-mail: lange.thomas@epss.hun-ren.hu

In this short summary, the reader is introduced to the Nagybözsöny village and surrounding environment. For deeper insight, the reader is referred to the literature.

Nagybörzsöny is located at the western margin of an andesitic volcanic complex in North Hungary. The Börzsöny Mountains belong to the oldest members of the extended Miocene to Quaternary calc-alkaline-type volcanism in the Carpathian-Pannonian Region (Karátson, 1995; Karátson et al., 2000; Harangi et al., 2007; 2024). The volcanic complex was formed about 14–16 million years ago, contemporaneously with the nearby Visegrád Mts. Although it comprises andesitic to rhyodacitic volcanic rocks, no direct connection to subduction was suggested but a relation to continental extension as part of the formation of the Pannonian Basin (Lexa & Konecny, 1974; Harangi et al., 2001; 2007; 2024). It is one of the oldest Miocene volcanic member of the Neogene volcanic chain surrounded by the Ipoly valley from the north and west, the Danube from the south, the Nógrád basin and Cserhát from the East. The whole volcanic evolution can be separated into two main episodes (Karátson et al., 2000): The initial stage was common with the Visegrád Mts, when predominantly garnet-bearing dacitic and rhyodacitic magmas extruded and formed a lavadome field (e.g., Nógrád castle hill, Bajdázó and Királyrét area; Harangi et al., 2001). The lava dome forming eruptions were occasionally associated with pumiceous pyroclastic flows. There was a gradual change in the erupted magma towards andesitic composition without garnet. This was followed by the build-up of the High Börzsöny composite volcano by andesitic lava dome extrusions and lava flows as well as block-and ash flow deposits. A major slope collapse could lead to the destruction of the volcanic edifice, followed by subsequent erosion. The volcanism was associated with modest Cu-Zn±Au, Ag epithermal ore mineralization, which is currently not economically significant (Csillagné Teplánszky et. al., 1980; Turi & Bertrandsson Erlandsson, 2025). According to geological and geochemical studies the volcanic rocks of the Börzsöny Mountains show high similarity with the magmatic rocks of the Visegrád and Burda Mountains that were segregating from the Börzsöny by the Danube and Ipoly, respectively (Karátson et al., 2007; Šimon et al., 2023). The Börzsöny Mountains lies on top of the W-E oriented Hubanovo-Diósjenő line that separates the southern Transdanubian Unit and the Vepor Unit (Koroknai et al., 2001). Fragments of latter can be found as crustal xenoliths in the oldest, most Si-rich volcanic deposits (Lange et al., 2017). The Börzsöny is surrounded by marine sediments of the Pannonian Lake (e.g., Lajta Limestone; Szilágy Marl) (Selmeczi et al., 2024). The preservation of the fauna varies from place-to-place. For example, villages of Zebegény, Letkés, Kemence are well known for the abundancy of shells, corals and echinodermata (Szeberényi et al., 2014; Radoslav & Kovács, 2025), whereas sandy limestones of Nagybörzsöny only preserve ichnofossils. In contrast, the embedment of the coral and ostrea is twofold, as they can also be found embedded in coarse debris (Fig. 1) owed to the graviational collapse of the southwestern part of the volcanic structure.

Figure 1. *Large Ostrea shells from the southeastern part of Nagybörzsöny.*

The high lithological variety of the Börzsöny mountains led to early settlements proven by the archeological and archeometrical studies in the vicinity of Nagybözsöny (Kóka I. personal communication). The earliest records of Nagybörzsöny dates back to 1108 under the name *Belsun* part of the Archbishop of Esztergom. The inhabitants soon realized the ore potential of the Börzsöny Mountains which led to significant gold and silver mining in the upcomming centuries being the second largest gold and silver supplier of the middle ages. The mining was mostly done by inhabitants of Schwabian and Saxon origin who intergrated into Nagybörzsöny. As a result, the Nagybörzsöny became bilingual – Hungarian, Schwäbisch with its own Nagybörzsöny dialect – from which unfortunately the Schwäbisch in the last decades became a dying language (Nagy & Márkus, 2014). Nevertheless, the bilingual history is well preserved in the village, most prominant being the village name Deutschpilsen and the german gothic text on the old gravestones in the graveyard. The oldest building of the village is the Saint Stefan church, built in the XIII. century by the Hungarians, simultaneously with the predecessor of the presently known Mining Church (Fig. 2) and the Saint Nicolas Church by the Germans. In the following centuries the mining continued mainly focusing on gold and silver, but more and more mineral species (such as galenite, sphalerite) were identified and documented[1]. The most interesting species are the Bi-Te minerals from which 5 species were first documented from Rózsa quarry, Nagybörzsöny (mindat.org; Szakáll & Fehér, 2025). Of these minerals, pilsenite and kanatzidisite have peculiar history and structures. Pilsenite (Bi_4Te_3) played a fundamental role in the discovery of the element tellurium, as it – along with its unknown constituent element – was discovered around the same time as nagyagite, the mineral from which Te was first described. Franz-Joseph Müller von Reichenstein (1740–1825) was an Austro-Hungarian mining engineer and mineralogist, a skilled mining officer working for the empire's mining administration. He analysed various ore minerals, particularly in gold mines (mostly in Săcărâmb which is located in the Transylvania region of Romania; it is called Nagyág in Hungarian, and also in Nagybörzsöny). In 1782, he noticed a new element in the mineral nagyagite not known before and this was identified also in the mineral found in Nagybörzsöny. He initially called this element "aurum problematicum", i.e. problematic gold because it was part of the gold ore but behaved chemically differently. Later, Martin Heinrich Klaproth confirmed this discovery and named the element tellurium in 1798. The type-locality became Săcărâmb, but Franz-Joseph Müller von Reichenstein's work in Nagybörzsöny strongly contributed to the discovery (Weeks, 1935). The mineral, Pilsenite, was later studied by Pál Kitaibel and named after the german name of Nagybörzsöny (Deutschpilsen) can be found in the Mineralogical Museum at the Eötvös Loránd University (Budapest) (Marshall & Marshall, 2003). To date, no additional specimens have been found in the Börzsöny Mountains. Kanatzidisite ($(BiSbS_3]_2[Te_2])$) is a recently discovered mineral (Bindi et al., 2023) that has a peculiar structure primarily interesting for the material science community. Its unique structure composes of a 'sandwich' structure formed by alternating $BiSbS_3$ double van der Waals layers separated by a distorted Te_2 tetrahedron layer. This structure provides new opportunities to better understand physical properties and the construction of Dirac semimetals (Bindi et al., 2023).

Figure 2. *The Miners' Church in Nagybörzsöny.*

In summary, Nagybörzsöny is a small village with a rich geological and cultural history, demonstrating how distinct disciplinaries can evolve together. The discovery of new mineral species, archeological remains and geosites of geo-heritage significance highlights the village's still largely untapped potential that hopefully will be presented at the upcoming geological conference.

References

Bindi L., Zhou X., Deng T., Li Z. & Wolverton C. (2023): Journal of the American Chemical Society, 145(33), 18227–18232.

Csillagné-Teplányszky B., Csongrádi I. J., Erkel A., Kakas Gy., Király E., Korpás L., Madaras I.A., Pentelényi L., Pintér A., Schönviszky L., Szabó Zs., Szalay L., Verő L. & Verőné Ákos É. (1980): Zárójelentés a Börzsöny-hegység központi terület 1970-1980 között végzett ércföldtani kutatásokról – Hungarian Geological Institute, Hungarian National Geological, Geophysical and Mining Data Repository.

Harangi Sz., Downes H., Kósa L., Szabó Cs., Thirlwall M.F., Mason P.R.D. & Mattey D. (2001): Journal of Petrology, 42, 1813–1843.

Harangi Sz., Downes H., Thirlwall M. & Gméling K. (2007): Journal of petrology, 48(12), 2261–2287.

Harangi Sz., Seghedi I. & Lukács R. (2024): Geological Society, London, Special Publications 554(1), SP554-2024-2084

Karátson D. (1995): Ignimbrite formation, resurgent doming and dome collapse activity in the Miocene Börzsöny Mountains. Acta Vulcanologica, 7, 107–119.

Karátson D., Márton E., Harangi Sz., Józsa S., Balogh K., Pécskay Z., Kovácsvölgyi S., Szakmány S. & Dulai A. (2000): Geologica Carpathica, 51(1), 325–343.

[1] https://www.arcanum.com/en/online-kiadvanyok/SzazMagyarFalu-szaz-magyar-falu-1/nagyborzsony-B041/nagyborzsony-summary-B325/

Koroknai B., Horváth P., Balogh K. & Dunkl I. (2001): International Journal of Earth Sciences, 90(3), 740–751.

Lange T.P., Vígh Cs., Kővágó Á. & Józsa S. (2017): 8th Assembly of Petrology and Geochemistry, Abstract Book, 100–102.

Lexa J. & Konečny V. (1974): Acta Geologica Hungarica, 18, 279–293.

Marshall J.L. & Marshall V.R. (2003): The Hexagon, 94(1), 1–8.

Selmeczi I., Fodor L., Lukács R., Szepesi J., Sebe K., Prakfalvi P. & Sztanó O. (2024): In: Babinszki E., Piros O., Csillag G., Fodor L., Gyalog L., Kercsmár Zs., Less Gy., Lukács R., Sebe K., Selmeczi I., Szepesi J. & Sztanó O. (eds.): Lithostratigraphic units of Hungary II. Cenozoic formations, 52–115. Supervisory Authority of Regulatory Affairs, Budapest.

Šimon L., Kollárová V. & Kováčiková M. (2023): Mineralia Slovaca, 55(2). 117–132.

Szakáll S. & Fehér B. (2025): Második kiegészítés a „Magyarország ásványai” című könyvhöz. Manuscript, Herman Ottó Museum, Miskolc.

Szeberényi J., Józsa S., Simon I., Kiss K., Bradák B. & Viczián I. (2015): Bulletin of the Hungarian Geological Society, 144(5), 367–384.

Turi J. & Bertrandsson Erlandsson V. (2025): 15th Assembly of Petrology and Geochemistry, Abstract Book, 88.

Weeks M.E. (1935): Journal of Chemical Education, 12(9), 403.

PROGRAMME

2nd October, Thursday – Morning

9:00	10:00		**Registration**
10:00	10:20	Réka LUKÁCS Samuel RYBÁR	**Opening ceremony**
1st oral session		**Chairperson:** György CZUPPON	
10:20	10:30	Dávid KARÁTSON	Tracing a 13.06 Ma phreatomagmatic ignimbrite from the Mátra Mts. to the Tokaj Mts.: a snapshot of the paleoenvironment of the Central Paratethys
10:32	10:42	Katarína ŠARINOVÁ	Hrabovec Tuff Member as a stratigraphic marker in the East Slovakian Basin
10:44	10:54	Mihovil BRLEK	From ignimbrites to residual deposits: tracing the record and linking the Oligo–Miocene volcanism and intense chemical weathering in the SW Pannonian Basin and the Dinarides (Alpine-Mediterranean region)
10:54	11:10		**Questions**
11:10	11:30		**Coffee break**
11:30	11:40	Milan KOHÚT Jörg OSTENDORF	Petrology of the andesitic rocks from the Slanské vrchy Mountains
11:42	11:52	Samuel RYBÁR	Geological setting, petrography, and geochronology of the Miocene vitro-crystal tuff from Kecerovské Peklaňy, East Slovak Basin (Transcarpathian Basin)
11:52	12:05		**Questions**
2nd oral session		**Chairperson:** Igor BROSKA	
12:05	12:15	Maria PÂRLEA	Unraveling trace elemental compositional variation by LA-ICP-MS mapping
12:17	12:27	László PALCSU	A review of isotope ratio analyses by MC-ICPMS in ATOMKI
12:29	12:39	Laurent VASSE	JEOL EPMA and SXES, tools and techniques
12:39	12:50		**Questions**
12:55	13:55		**Lunch**

2nd October, Thursday – Afternoon

13:55	15:10	**Poster session**	
15:10	15:30	**Coffee break**	
15:30	16:10	Jaroslav LEXA Peter KODĚRA	**Plenary talk:** Structural, magmatic and metallogenetic evolution of the Štiavnica Stratovolcano
16:10	16:20	**Questions**	
3rd oral session		**Chairperson:** Tivadar M. TÓTH	
16:20	16:30	Dariana CHIVULESCU	Quantification of Salta rift extension
16:32	16:42	Adrienn TATÁR	Traces of a Late Miocene regional fluid flow in an Early Miocene volcanic sequence near Paks (Hungary)
16:42	16:55	**Questions**	
16:55	17:10	**Break**	
17:10	17:20	Judit TURI	Trace element analysis of ore minerals from the Börzsöny mountain
17:22	17:32	Attila DEMÉNY	On the origin of the mysterious carbonado diamond
17:34	17:44	Balázs KÜZMÖS	A mineralogical, petrographical, geochemical, and noble gas analysis of two Saharan meteorites
17:46	17:56	Zoltán VÁCI	Differentiation and crust formation on the ureilite parent body
17:56	18:10	**Questions**	
4th oral session		**Chairperson:** Boglárka Mercédesz KIS	
18:15	18:25	Beatrix Boglárka BALÁZS	New deposit model of the Ostra barite-polymetallic hydrothermal system (Eastern Carpathians, Romania)
18:27	18:37	Botond G. GERECZI	Accumulation of technology metals in sphalerite: Dependence on formation conditions (temperature, metamorphic overprint)
18:39	18:49	Viktor JÁGER	The first ore-prospecting sonic drilling in the Mecsekalja Shear Zone, South Hungary: preliminary results
18:49	19:10	**Questions**	
19:20	20:20	**Dinner**	

4th October, Saturday – Morning

8:30	8:50	Sierd CLOETHING	**Plenary talk:** Coupled surface to deep Earth processes: Perspectives from TOPO-EUROPE with an emphasis on climate- and energy-related societal challenges
5th oral session		**Chairperson:** Milan KOHÚT	
8:52	9:02	Igor BROSKA	Variscan granites in the Western Carpathians: current view on their rapid formation and source
9:04	9:14	Máté SZEMERÉDI	Petrology, zircon U–Pb dating, and correlations of Variscan S-type granitoids in the Tisza Mega-unit
9:16	9:26	Adriana STOICA	Assimilation of (meta-)igneous material: insights from LA-ICP-MS trace element mapping of garnetites from South Apuseni andesites
9:26	9:40		**Questions**
9:40	9:50	Vlad-Victor ENE	Adakite-like and normal calc-alkaline suites from the South Apuseni Mountains: a phenocryst story
9:52	10:02	Barbara CSERÉP	Traces of magma evolution recorded in amphibole textures and compositions: Insights from the last 160,000 years of Ciomadul Volcano, Romania
10:04	10:14	Emese PÁNCZÉL	Petrogenesis and amphibole–melt trace element partitioning of the 156 ka Haramul Mic crystal-rich dacite, Ciomadul, Romania
10:14	10:30		**Questions**
10:30	10:50		**Coffee break**
10:50	11:10	Mihai DUCEA	**Plenary talk:** Magmatic architecture of continental crust in convergent settings
11:10	11:20		**Questions**
6th oral session		**Chairperson:** Samuel RYBÁR	
11:20	11:30	Aliz ZEMENY	Reoccurring crystal patterns of the Taranaki transcrustal magmatic system (65-34ka), New Zealand
11:32	11:42	Kende Fülöp SZŰCS	Noble gas isotopic composition in olivine phenocrysts from Miocene to Pliocene basaltic rocks of the Pannonian Basin
11:42	11:52		**Questions**
11:55	12:10		**Break**
12:10	12:20	Boglárka Mercédesz KIS	The CO_2-rich gas emissions of the Carpathians: Geochemistry and origin of fluids
12:22	12:32	István CSIGE	Sampling strategy and quantification of extremely inhomogeneous focused and diffuse CO_2 efflux
12:34	12:44	Abazar M.A. DAOUD	PCA, clustering, and Geo-AI-based sedimentological and petrographic analysis for depositional environment interpretation of Paleozoic–Mesozoic sedimentary sequences: evidence from Wadi Halfa, Northern Sudan
12:44	12:55		**Questions**
13:00	14:00		**Lunch**

4th October, Saturday – Afternoon

14:00	14:50	**Poster session**	
14:50	15:00	**Coffee Break**	
7th oral session		**Chairperson:** Máté SZEMERÉDI	
15:00	15:10	Gabriella OBBÁGY	Mineral impurities along the graphite value chain
15:12	15:22	Róbert ARATÓ	What to do with geochemical data from heterogeneous geological materials – a graphite perspective
15:24	15:34	Balázs KOROKNAI	2D S-wave reflection seismic survey in the West-Mecsek Mts.: new insights into shallow geology and neotectonics
15:36	15:46	Tivadar M. TÓTH	Unified model of the metamorphic basement of the Southern Great Plain
15:46	16:05	**Questions**	
16:05	16:15	Szilvia KÖVÉR	Reinterpreting the role of evaporite-driven deformation in the inner western Carpathians during the opening and closure of the Neotethys Ocean
16:17	16:27	Veronika SZILÁGYI	Characterization of medium-temperature fired iron-free clays based on microtexture and mineralogical composition
16:29	16:39	Péter NÉMETH	Metastable aragonite formation
16:41	16:51	György CZUPPON	Cave monitoring in Hungary with special focus on Mg and Ca isotopes of drip water and carbonate precipitates
16:51	17:10	**Questions**	
17:10	17:30	Szabolcs HARANGI	**Closing ceremony**

POSTERS

1	Csilla BALASSA	Aeschynite and euxenite group minerals from Vesszős Valley, Lillafüred, Bükk Mts., Hungary
2	Barbara BEKE	Structurally controlled silica precipitation in the Hárshegy Sandstone: evolution of multi-stage fault damage zones during the rifting of the Pannonian Basin
3	Karolina BORDÁS Margaréta GAZSI	Petrological and geochemical investigation of a cataclasite occurence on the western slope of the Odvas-hegy (Budaörs, Hungary)
4	György CZUPPON	Preliminary results of recently growing speleothem from the Szent István Cave, Bükk Mountains, Hungary
5	Erika KERESKÉNYI György CZUPPON	Preliminary results of monitoring investigations of the Szent István Cave, Bükk Mountains, Hungary
6	László FODOR	Migration of deformation, basin subsidence, magmatism in the extensional Pannonian Basin: good fit between numerical models and observations
7	Margaréta GAZSI	Zircon U-Pb geochronology and volcanology of the pryroclastic rocks of the Gelénes-1 borehole (Hungary)
8	Dorka GOMBOS Kitti ANDRÁSI	Volcanological and petrographic reassessment of borehole Sátoraljaújhely-8, Northeast Hungary
9	Iván GYENES	Copper and silver ore potential in the Western Mecsek
10	Krisztina HAJDU	Control of effusive and explosive eruptions of Ciomadul Volcano: constraints by apatite composition
11	Ervin HRABOVSZKI	Multiple vein formation events in the Western Mecsek area
12	Máté KARLIK	Reconstructing the past: preliminary paleoenvironmental data from lakes in the Carpathians
13	Thomas Pieter LANGE	The role of fluid molecules in mantle mineral phase transformation
14	Réka LUKÁCS	Zircon fingerprinting reveals the magnitude, tempo and size of Early to Mid-Miocene explosive volcanism in the Pannonian Basin
15	Tamás MÜLLER	Carbon isotope chemostratigraphy of the Jenkyns Event in Hungary
16	Norbert NÉMETH	Mapping of metavolcanics in the southeastern part of the Bükk Mts., Hungary
17	Alexandra ORBÁN	Preliminary results of hydrogen measurements in the South Apuseni Mountains (Romania)
18	Emese PÁNCZÉL	Geochemical composition of olivine phenocrysts from the alkaline basalts of the Persani Volcanic Field with a focus on noble gas isotope content - Insights into the characteristics of the magma source region
19	Bálint PÉTERDI Tamás SÁGI	Macrolithic finds made of metabasites from Csanádpalota – Földvár, SE Hungary (preliminary archaeometric results)
20	Félix SCHUBERT	Do petroleum inclusions genuinely reflect the original fluid composition?
21	Aya S. SHEREIF	Geochemical and spectrometric characterization of natural radioelements (^{238}U, ^{232}Th, and ^{40}K) in some granitoid rocks from the Central Eastern Desert, Egypt
22	Döme Zsombor SZABÓ	Insights into the structural evolution and mineral vein development in the Juhhodályvölgy Marble (Ófalu, Goldgrund-valley)
23	Réka SZALAY	A CO_2 island in a hydrocarbon sea – the case study of the gas emissions of Slănic Moldova, Eastern Carpathians, Romania
24	Veronika SZILÁGYI	Polished stone tool assemblage of Late Neolithic Öcsöd-Kováshalom site

ABSTRACTS

WHAT TO DO WITH GEOCHEMICAL DATA FROM HETEROGENEOUS GEOLOGICAL MATERIALS – A GRAPHITE PERSPECTIVE

Róbert Arató*, Gabriella Obbágy, Valentina Dietrich & Frank Melcher
Montanuniversität Leoben, Chair of Geology and Economic Geology, Leoben, Austria
* E-mail: robert.arato@unileoben.ac.at

Graphite is a critical and strategic raw material in major economies worldwide. It is used in numerous applications due to its extraordinary chemical and physical properties. Given its fundamental role in energy storage, responsible sourcing of graphite is particularly important. The European Union has set ambitious goals, as outlined in the Critical Raw Materials Act, to ensure the responsible sourcing of critical raw materials. Among these goals is the stipulation that no more than 65% of any critical raw material should be imported from a single third country by 2030. However, there is currently no routine methodology available to distinguish between different natural graphite deposits.

The EU-funded Horizon project, MaDiTrace (Material & Digital Traceability for CRM Certification), aims at reinforcing the transparency, reliability and sustainability of critical raw material supply chains, with a special focus on key commodities for battery and magnet production, including natural graphite. This collaborative effort involves four institutes, each focusing on a specific critical raw material: lithium (BRGM, France), cobalt (GTK, Finland), natural graphite (University of Leoben, Austria), and rare earth elements (Ghent University, Belgium). The project's objectives include developing analytical protocols for both laboratory and on-site fingerprinting, incorporating these protocols into certification schemes, and finally into so-called digital product passports. Analytical fingerprinting is used for differentiating between various natural deposits and identifying material characteristics that can be tracked throughout the value chain, from raw material to final product.

Graphite ores are typically extracted from heterogeneous geological environments with ore contents usually below 40%. Raw ore is then crushed and floated, and the resulting concentrates – with typical graphite contents around 95% – are traded worldwide.

In this contribution, we present results acquired by bulk analytical methods, such as inductively coupled plasma mass spectrometry (ICP-MS) and instrumental neutron activation analysis (INAA) as well as by in-situ methods on a comprehensive set of pressed graphite pellets. In-situ methods applied here include laser induced breakdown spectroscopy (LIBS) via benchtop and handheld instruments as well as laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS).

Solution ICP-MS analysis of graphite concentrates shows a wide range of detectable elements and very well reproducible results on different aliquots from the same concentrate. The results are well comparable with trace element concentrations obtained by INAA.

In order to better understand the origin of elemental anomalies detected by bulk techniques, in-situ techniques were also applied. LIBS generates multi-elemental data at an unprecedented speed even from samples with non-ideal ablation characteristics, such as pressed graphite pellets. The generated data was used for constructing elemental maps to shed light on the chemical distribution of elements in the concentrates. Chemical inhomogeneities are omnipresent in all studied concentrates. Based on the spatial relationship of the detected elements, it is also obvious that most chemical impurity elements stem from minerals, which are intermixed and/or intergrown with graphite flakes. The resulting chemical heterogeneity of the concentrates serves as a prominent fingerprint of individual deposits. On the other hand, the heterogeneity is also omnipresent between different samples of the same deposit and even within individual samples. This poses a significant challenge for LIBS and LA-ICP-MS analyses and raises the question if representative analysis of graphite concentrates via in-situ techniques is even possible. We test various approaches with both techniques and compare the outcome with the results obtained by bulk geochemical techniques.

For battery-specific applications, graphite concentrates are purified by alkali-autoclave leaching and/or hydrofluoric acid to reach a purity of at least 99.95%. Despite the fact that most of the above-described geochemical signature is removed by this process, the very low detection limit of the applied techniques also enables the traceability along the value chain to a certain extent.

This study was funded by the European Union under grant agreement no. 101091502, project MaDiTrace – Material and Digital Traceability for the Certification of Critical Raw Materials, coordinated by the French Geological Survey (BRGM).

AESCHYNITE AND EUXENITE GROUP MINERALS FROM VESSZŐS VALLEY, LILLAFÜRED, BÜKK MTS., HUNGARY

Csilla Balassa*, Norbert Németh, Ferenc Kristály, Sándor Szakáll & Délia Bulátkó-Debus
University of Miskolc, Institute of Exploration Geosciences, Miskolc, Hungary
* E-mail: csilla.balassa@uni-miskolc.hu

In Vesszős Vallley, Lillafüred, Bükk Mts. rare earth (REE)-Nb-Ti-oxide minerals were detected with EDX, in high field strength element enriched siliciclastic rock bodies (Németh et al., 2023). Low resolution of the technique as well as the usual small grain size (~10 micrometers) do not allow the correct identification of the exact mineral phases. Recently it has become possible to measure the composition more accurately with WDX in two rock samples (N4 and N6) from nearby exposures of two HFSE enriched beds. Based on the results, the chemical composition is roughly uniform within a given sample, but different between the two samples.

Ercit (2005) developed a canonical discrimination method based on the oxidic weight percent of the measured chemical elements, to distinguish between the various REE-Ti-oxide minerals (pyrochlore, samarskite, aeschynite / euxenite, fergusonite group minerals). Based on this method, the minerals from the Vesszős Valley are belonging to the aeschynite or euxenite groups, which are generally connected to pegmatites and carbonatites. Their general mineral formula can be written as AB_2O_6, where A = REE, Y, Ca, Th, U and B = Nb, Ta, Ti. Because of structural differences between the two mineral groups, aeschynite minerals are generally enriched in LREEs, while euxenite minerals in HREEs. Ewing (1974) suggest the following inequality to differentiate between the two groups: $LREE_2O_5 > 0.326\ TiO_2 - 0.060\ Nb_2O_5 + 3.1$. If the left-hand value is higher, the mineral can be identified is aeschynite, otherwise as euxenite. However, not all researchers agree that this statement is true (Guastoni et al., 2019). If we accept the statement, sample N4 contains aeschynite-(Nd), while sample N6 euxenite-(Y), based on the dominant REE cations in the A site. Calculated average chemical formulas based on 6 oxygen anions as follows: $(Ca_{0.2}\,Th_{0.2}\,Y_{0.1}\,LREE_{0.34}\,HREE_{0.11})\,(Ti_{1.1}\,Nb_{0.7}\,Si_{0.1}\,Fe_{0.1})\,O_6$ and $(Ca_{0.2}\,Y_{0.3}\,LREE_{0.07}\,HREE_{0.22}\,Fe_{0.2})\,(Ti_{0.8}\,Nb_{1}\,Si_{0.1}\,Fe_{0.1})O_6$. Dominant cations in the A site are LREEs (sample N4) and HREE+Y (sample N6), while in the B site Ti (sample N4) and Nb (sample N6). Substitution relationships exist within both positions, as well as between the two positions. The most characteristic substitution vectors are ${}^{A}Ca\,{}^{A}(U,Th)\,{}^{A}(Y,REE)_{-2}$ (sample N4) and ${}^{A}(U,Th)\,{}^{B}Ti\,{}^{A}(Y,REE)_{-1}\,{}^{B}(Nb,Ta)_{-1}$ (sample N6). Chemical composition of the aeschynite/euxenite minerals depend on more factors. Negative Eu- and Y-anomalies and fractionation values such as U / (U+Th) and Y / (Y+REE) are at least partly inherited from the chemical composition of the fluid responsible for the mineralization, while other features, such as negative Yb and Nd anomalies exist probably due to the difference in the partition coefficients of the various occurring rare-element bearing-minerals (in addition to REE-Nb-Ti-oxides monazite, cheralite, zircon, Nb-bearing Ti-oxides) and on their quantity, as well as on structural factors.

Presence of the aeschynite and euxenite minerals indicate a hypothetical magmatic source body, from where rare elements can be originated.

References

Ercit T.S. (2005): The Canadian Mineralogist, 43(4), 1291–1303.

Ewing R.C. (1974): Mineralogy of Metamict Rare Earth AB2O6-type Niobium-tantalum-titanium Oxides. Stanford University. Department of Geology.

Guastoni A.L., Secco L., Škoda R., Nestola F., Schiazza M., Novák M. & Pennacchioni G. (2019): Minerals, 9(5), 313.

Németh N., Kristály F. & Balassa Cs. (2023): Journal of Geochemical Exploration, 246, 107159

NEW DEPOSIT MODEL OF THE OSTRA BARITE-POLYMETALLIC HYDROTHERMAL SYSTEM (EASTERN CARPATHIANS, ROMANIA)

Beatrix Boglárka Balázs[1]*, Árpád Ádámcsik[2], István Márton[3], Szabolcs Orbán[4] & Gabriella B. Kiss[1]
[1] Eötvös Loránd University, Department of Mineralogy, Budapest, Hungary
[2] GEOINFORM Ltd., Algyő, Hungary; [3] Stockwork Geoconsulting Ltd., Serbia; [4] Goldron Geoconsulting Ltd., Romania
* E-mail: balazsbboglarka@gmail.com

The barite-polymetallic mineralization of Ostra, located in the Tulgheș Group in the Eastern Carpathians (Romania), has been interpreted as an epigenetic barite occurrence (Ianovici, 1966), with little attention paid to its polymetallic features. However, our recent study reveal that the deposit is considerably more complex than previously thought, and may bear critical raw material potential.

Systematic field mapping revealed several massive sulfide lenses associated with barite at different levels of the abandoned Ostra open-pit. These sulfide bodies are hosted by altered rhyolitic metavolcanic rocks. Distinct zoning patterns were observed: the zones of the main fluid flow are rich in pyrite, sphalerite, galena, and chalcopyrite with barite occurring more rarely, whereas distal zones contain predominantly barite with disseminated sulfides. Hydrothermal alteration is present in the host rock, consisting of kaolinite, illite, dickite, and alunite.

Petrographic observations revealed that pyrite is the most abundant sulfide (up to 60% in the massive sulfide lens), occurring in various textures including framboidal and colloform forms. Sphalerite (up to 10%) typically appears with galena and chalcopyrite, while chalcopyrite is less common (<5%) and mostly found as intergrowths. These sulfides together with fahlore are present also in the distal parts, where they associate with barite.

The earliest stage of ore formation is represented by framboidal and colloform pyrite aggregates, often intergrown with tabular or rosette-type barite crystals. This first generation also includes larger (>0.2 mm) idiomorphic crystals of sphalerite and galena, occurring in nests within the host rock. A second stage is characterized by finer-grained (0.06–0.2 mm) pyrite crystals and the appearance of chalcopyrite, typically intergrown with earlier-formed sphalerite and galena.

Barite formation occurred in at least two distinct stages: an early syngenetic, associated with massive sulfide formation and a later vein-type generation that reflects epigenetic remobilization. Barite crystals exhibit various morphologies, ranging from rosette-shaped aggregates in sulfide-rich zones to euhedral tabular crystals in strongly altered, clay-rich host rocks. Additionally, large massive barite bodies found further from the massive sulfides dominate the deposit and were historically the main targets for mining.

Fluid inclusion analysis on barite in association with the sulfides revealed a homogeneous parent fluid. The homogenization temperatures (i.e., minimum formation temperatures) are between 145 and 193 °C, and the salinities are between 5.3 and 7.6 wt% NaCl equiv., characteristic of low-temperature submarine hydrothermal systems. Raman spectroscopy confirmed the presence of methane. All results indicate dynamic pressure-temperature changes during mineralization.

Whole-rock geochemical analyses revealed considerable variability in metal contents among sulfide lenses, especially for precious metals like Au, Ag. For instance, Au concentrations reach up to 13 ppm in some lower mine lenses, but are below 1.2 ppm in upper zones, likely reflecting different distances from the main upflow zone of the hydrothermal system.

These variations reflect structural, lithological, and fluid evolution controls within the hydrothermal system. Sulfide lenses at Leșu Ursului (~2–3 km from Ostra) formed in higher-temperature, proximal settings and are Cu-rich (1–3 wt%) but barite-poor. In contrast, the Ostra lenses, formed in lower temperature conditions are characterized by abundant barite, higher Pb-Zn, and lower Cu concentrations (~1.4 wt%), suggesting a more distal position within the hydrothermal system.

Overall, these results support a new genetic model for the Ostra mineralization, which formed syngenetically via submarine hydrothermal (VMS-type) processes. Besides, the later (e.g., metamorphic) remobilization may have contributed to the formation of epigenetic-type barite.

References

Ianovici V., Pitulea G. & Lemne G. (1966): Studii și cercetări de geologie, geofizică, geografie. Seria geologie 11(2), 331–340.

STRUCTURALLY CONTROLLED SILICA PRECIPITATION IN THE HÁRSHEGY SANDSTONE: EVOLUTION OF MULTI-STAGE FAULT DAMAGE ZONES DURING THE RIFTING OF THE PANNONIAN BASIN

Barbara Beke[1]*, Melinda Fialowski[1], Tamás Müller [2,3], Félix Schubert [4], Réka Lukács[2,5], Marcel Guillong[6], Szabolcs Harangi[2,5] & László Fodor[1,7]

[1] Eötvös Loránd University, Department of Geology, Budapest, Hungary
[2] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[3] HUN-REN-MTM-ELTE Research Group for Paleontology, Budapest, Hungary
[4] University of Szeged, Department of Mineralogy, Geochemistry and Petrology, Szeged, Hungary
[5] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[6] ETH Zürich, Department of Earth Sciences, Zürich, Switzerland
[7] HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary
* E-mail: barbara.beke@gmail.com

Brittle fracture zones as passages for fluid migration within the shallow crust results in substantial petrophysical changes that strongly influence deformation localisation at evolved inhomogeneities in the host rock. Structural diagenetic evolution of multi-stage fault zones with different generations of deformation elements and modes of silica cementation was investigated in the pre-rift (Oligocene) Hárshegy Sandstone using a combination of structural, burial, micropetrographic, geochemical and geochronological analyses. The established relationships between distinct evolutionary steps can be correlated with burial and volcanic phases; as the initially porous sediment was structurally and diagenetically hardened and then softened, and the geometry of the fault system changed during the volcanic activity associated rifting. The deformation mechanism shows a progressive change from proto-cataclasis to more advanced cataclasis, followed by the development of DB faults with siliceous slip surfaces and a transition to veining. The age of syn-tectonic, silica-associated fracture systems is constrained by the diagenetic state of the host rock, the related deformation mechanisms, and the geometric pattern. The geometry of siliceous fractures is identical to map-scale faults and early type deformation bands occurring in the ~15.3 Ma pyroclastic rocks bordering the sandstone to the north and partly to the forming dykes (15.4 Ma) to the east, within the Cserhát Hills (Juhász et al., 2025). Silica precipitation can primarily be related to structurally controlled fluid pulses and rapid cooling as fluids pass through the propagating syn-rift fractures. Such large-scale hydrothermal fluid migration, resulting in tens of km^2 siliceous cementation, was facilitated by the onset of volcanic activity. The accompanying general increase in fluid pressure may have led to the permutation of the maximum and the intermediate principal stress axes. As a result, the early syn-rift extension switched to a transtension during the main syn-rift phase. Meanwhile, vertical axis rotations also contributed to the change in the apparent stress field, resulting in the development of an orthorhombic fault pattern. The developed fault sets with three characteristic orientations and frequent reactivations are analogous to an oblique rift at the rift margins (Clifton et al., 2000). This pattern may have formed in relation to an inherited structural weakness zone. Mesozoic rifting, Cretaceous inversion and Paleogene strike-slip faulting, as potential weakness zones, are assumed, but requires further investigation at a larger scale.

References

Clifton A.E., Schlische R.W., Withjack M.O. & Ackermann R.V. (2000): Journal of Structural Geology, 22, 1491–1509.

Juhász D., Chiara, L., Benkó Zs., Sigmundsson F., Beke B., Bergerat F., Fialowski M. & Fodor L. (2025): Tectonophysics, 906(4), 230722

PETROLOGICAL AND GEOCHEMICAL INVESTIGATION OF A CATACLASITE OCCURRENCE ON THE WESTERN SLOPE OF THE ODVAS-HEGY (BUDAÖRS, HUNGARY)

Karolina Bordás*, Margaréta Gazsi & Tamás Sági
Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
* E-mail: bordas.karolina92@gmail.com

Pelikán (2016) mentioned an occurrence of the Sukoró Lamprophyre Formation (formerly Budakeszi Picrite) on the western slopes of the Odvas-hegy in Budaörs (Hungary), penetrating the Budaörs Dolomite. It was mentioned also by Haas & Budai (2004) without classification of the formation. Since its field and macroscopic petrological properties do not match either picrite or lamprophyre, and we could not find more information about the outcrop in the literature, we decided to further examine it as part of a research project nominated for the National Conference of Scientific Students' Association (OTDK) (Bordás & Gazsi, 2024).

The main, S-N striking part of the outcrop is 5 m long and 35 cm wide. It has two smaller sections on the northern and southern end of the outcrop on its eastern side, which are perpendicular to the main part. The rock is reddish brown, strongly weathered with a poorly developed wavy foliation.

Several thin sections were examined. Detailed petrographical description was prepared by polarizing and scanning electron microscope (SEM) at the Department of Petrology and Geochemistry, Eötvös University. Phase analyses of some selected minerals by Raman spectroscopy and determining the mineral composition of the whole rock by powder X-ray diffraction were also carried out at the Department of Mineralogy, Eötvös University. Main elements composition and indicative minor elements composition have been determined by SEM EDS. Additional petrographical and mineral chemical investigations were carried out on heavy mineral separates.

Based on petrographical information, the sample has a cataclastic fabric and it is dominantly composed of two types of clasts. Clast I. means irregularly shaped grains with felsitic texture, it is quartz-rich and only rarely contain pseudomorphs of feldspar. The elongation direction of the clasts is sometimes parallel to the foliation/cracks running through the rock. Their internal structure is chaotically vesicular or slightly oriented. We assume that these clasts are of a recrystallized pumice origin. Clast II. mainly consists of clay mineral pseudomorphs after feldspar. In many cases, these clasts also show slight orientation parallel to the cracks and outcrop-scale foliation of the rock. It also contains columnar/stubby limonite/jarosite pseudomorphs after pyroxene. The jarosite often contains Sr. Based on Raman spectroscopy this variant is slottaite, which was previously not known from Hungary. Based on its modal composition and texture, Clast II. may have originally been andesite. The investigated rock also has a significant barite and apatite content and electron microscopic studies suggest that it also contains cinnabar. These, together with the large amount of clay minerals indicate hydrothermal processes/alteration. Based on its textural characteristics, the rock is cataclasite. Its protolith may have been a breccia/sandstone consisting of andesite and rhyolite clasts. Based on literature data the age of the protolith is probably Late Eocene and the hydrothermal processes following cataclasis are Early-Middle Miocene.

References

Bordás K. & Gazsi M. (2024): Manuscript for the National Conference of Scientific Students' Association, ELTE Department of Petrology and Geochemistry, Budapest.

Haas J. & Budai T. (2004): In: Haas J. (ed.): Magyarország geológiája. Triász. ELTE Eötvös Kiadó, Budapest, pp. 25–124.

Pelikán P. (2016): In: Gyalog L., Maros Gy. & Pelikán P. (eds.): Budapest geokalauza = Budapest geoguide, Geological and Geophysical Institute of Hungary, Budapest, pp. 149–153.

FROM IGNIMBRITES TO RESIDUAL DEPOSITS: TRACING THE RECORD AND LINKING THE OLIGO–MIOCENE VOLCANISM AND INTENSE CHEMICAL WEATHERING IN THE SW PANNONIAN BASIN AND THE DINARIDES (ALPINE-MEDITERRANEAN REGION)

Mihovil Brlek[1]*, Nina Trinajstić[1], Vlatko Brčić[1], Sanja Šuica[2], Duje Kukoč[1], Ivan Mišur[1] & Réka Lukács[3,4]
[1] Croatian Geological Survey, Department of Geology, Zagreb, Croatia
[2] University of Zagreb, Faculty of Science, Department of Geology, Zagreb, Croatia
[3] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[4] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
* E-mail: mihovil.brlek@hgi-cgs.hr

The presence of volcaniclastic deposits in various Croatian Oligocene–Miocene basins was historically recognized (i.e., North Croatian Basin, Dinaride Lake System, and Hrvatsko Zagorje Basin), however, hitherto their stratigraphic and petrological potential, as well as their regional significance, has not been fully acknowledged. As well, the pioneering work from the 1970s on the Eocene to Miocene residual deposits in the Dinarides, besides highlighting their importance as markers of intense chemical weathering during Paleogene and Neogene, tentatively suggested their link with the contemporaneous yet unspecified (regional) volcanism.

The PYROSKA project (Miocene syn-rift evolution of the North Croatian Basin, Carpathian–Pannonian Region: a multi-proxy approach, correlation and integration of sedimentary and volcanic record; UIP-2019-04-7761), funded by the Croatian Science Foundation, used a multi-proxy approach on volcaniclastic (e.g., ignimbrites, ashfalls, and volcaniclastic turbidites) and residual deposits (e.g., karst clayey bauxites and bauxitic clays) of the SW Pannonian Basin and the Dinarides, including volcanology, sedimentology, petrology, zircon petrochronology, as well as chemical and isotopic fingerprinting of volcanic glass. Such an approach, combined with existing datasets (e.g., from the Bükkalja Volcanic Field, Hungary), significantly furthered our previous knowledge on the volcanic history of the source region, providing additional information on the topics such as frequency, extent, scale, tephrostratigraphy, and petrogenesis of the Carpathian–Pannonian Region (CPR) silicic volcanism during the Early–Middle Miocene, as well as the mechanisms of emplacement of volcaniclastic deposits, timing of the evolution of the basins, and changing depositional environments. Additionally, it provided a window into Dinaridic residual record of regional silicic volcanism, intense chemical weathering, re-sedimentation, and basin evolution intertwined during (Eocene–)Oligo–Miocene in the Alpine-Mediterranean region.

Recognition of at least eleven regionally extensive Early to Middle Miocene volcanic events (from ~18.1 Ma to ~14.3 Ma) suggests that large volume CPR ignimbrite-forming eruptions were more frequent, widespread and larger than previously considered. Based on observations so far of potential areal distribution and estimated thicknesses of ~18.1 Ma Kalnik, ~17.3 Ma Eger, and ~17.1 Ma Mangó massive pyroclastic density current deposits across the CPR, these three widespread outflow ignimbrites represent intermediate to large caldera-forming ignimbrites. Further research should provide additional insights into the volcanic history of the CPR.

Based on the integrated zircon geochronological and Hf isotopic data, the signal of Early–Middle Miocene CPR eruptions was also recorded in the Dinaridic residual deposits overlain by Dinaride Lacustrine System deposits. However, besides the dominant Miocene dates, the residual zircons of Oligocene and Eocene age, as well as of subordinate Mesozoic and Paleozoic age, were also recorded. This highlights the contribution of the CPR and potentially various Paleogene volcanic sources across the Alpine-Mediterranean region (e.g., Internal Dinarides, Rhodopes, and/or Periadriatic-Mid-Hungarian volcanic centres) to the Dinaridic sinks, but also implies complex local and regional geological setting and emplacement mechanisms of the residual deposit precursor material(s) and its likely concomitant intense chemical weathering at the mid-latitudes during Oligo–Miocene.

VARISCAN GRANITES IN THE WESTERN CARPATHIANS: CURRENT VIEW ON THEIR RAPID FORMATION AND SOURCE

Igor Broska[1]*, Milan Kohút[1], Sergii Kurylo[1] & Maria Maraszewska[2]
[1] Earth Science Institute, Slovak Academy of Sciences, Bratislava, Slovakia
[2] Institute of Geophysics, Polish Academy of Sciences, Warszawa, Poland
* E-mail: igor.broska@savba.sk

The mineralogical and geochemical character of the Variscan Western Carpathian granites (VWCG) determines the protolith and the ratio of mixing between mantle and lower crustal material. The findings of Ediacaran–Cambrian zircon in the VWCG indicate their recycling from (Cadomian)-Cenerian sources. Variscan granites with detected inherited zircon show a mixing array of crustal and mantle derived magmas evident from whole-rock $\varepsilon Nd_{(350)}$ = +1.6 to –5.9 and zircon $\varepsilon Hf_{(350)}$ = +8.3 to –8.7. Since preserved Cenerian zircons yielded $\varepsilon Hf_{(500)}$ values ranging from +9.6 to –5.5, the Variscan granites could have been sourced from the Cenerian subduction-accretionary complex; i.e., in the sense of Zurbriggen (2017), it was dominated by a peraluminous crustal source mixed with a mafic component of the mantle. High Sr/Y and La/Yb ratios give some of the granitic rocks an "*adakitic*" *character s.l.*, which mostly indicates their formation in deep lower crustal conditions by partial melting in the garnet stability field, in disequilibrium with plagioclase at reduced water contents. These I-(S) granites became more S-type during emplacement, changing their mineralogy and isotopic records. In general, for the heyday of the Variscan granites of the Western Carpathians during lower Carboniferous (Tournaisian stage), the main source of heat was probably asthenospheric upwelling due to the slab break-off geodynamics, that occurred within the NW Variscan subduction of the narrow Balkan-Carpathian Ocean. Such a geodynamic scenario would be crucial for triggering the large scale granite formation after the opening of pathways for increased heat and fluid flow from the uplifted asthenosphere. This event became effective in the late Devonian period after the collision. The first granite masses are diatexites connected with crustal exhumation following the initial slab break-off dynamics after terminated of subduction. The crustal blocks (due to buoyancy) started to exhume, forming the Devonian diatexites in a decompression regime. Up to now, dated diatexites show age span of 362 to 360 Ma.

To summarize SHRIMP age determinations of granites: the main formation event of calc-alkaline granitic rocks in the Western Carpathians occurred after the Devonian period in time range ca. 359–342 Ma. The granite datings indicate some magmatic intervals: (1) 359–358 Ma, an episode with formation of tonalite / granodiorite suites with prevailing I-type affinity, (2) 355–353 Ma, the culmination of granodiorite/granite formation, and (3) 347–342 Ma, a period of hot granotonalites. A gradual Variscan collapse occurred with the termination of granite formation, leading to a large-scale Permian rifting regime. In general, late granites (granotonalities) formed from hotter melts, which indicates the absence of mafic microgranular enclaves in them compared to the formation of earlier tonalites/granodiorites, which had these enclaves, albeit in small numbers. Late granites are H-types according to the classification of Castro et al. (1999). The presence of former mafic melt dissolved in crustal felsic melt well documents the Visean Kriváň granodiorite with preserved cores of plagioclase with high basicity (An56). The high degree of melt mixing is indicated by the multi-stage formation of plagioclase and Kfs. The high primary temperatures of these late magmas indicate the presence of antiperthites. We can assume that some compositional features of the late granites / granotonalites could have derived from very hot deep crustal melts formed in the MASH zone and the main heat source for such melting was the gradual and significant rise of the asthenosphere. In conclusion, the formation of the Variscan granites in the Western Carpathians can be linked to the long-term influence of the asthenosphere on the crust that occurred during the Paleo-Adrian collision, as proposed by Neubauer et al. (2022) for the formation of the Variscan granites of the Eastern Alps.

References

Castro A., Patiño Douce A.E., Corretgé L.G., De La Rosa J.D., El-Biad M. & El-Hmidi H. (1999): Contributions to Mineralogy and Petrology, 135, 255–276.

Neubauer F., Liu Y., Dong Y., Chang R., Genser J. & Yuan S. (2022): Earth-Science Reviews, 226, 103923

Zurbriggen R. (2017): International Journal of Earth Sciences, 106, 517–529.

QUANTIFICATION OF SALTA RIFT EXTENSION

Dariana Chivulescu[1]* & Mihai Ducea[1,2]
[1] University of Bucharest, Faculty of Geology and Geophysics, Bucharest, Romania
[2] Department of Geosciences, University of Arizona, Tucson, USA
* E-mail: dariana04@yahoo.com

The Salta Rift, an aborted extensional basin system located in NW Argentina, represents a key example of intracontinental rifting associated with the early stages of Gondwana fragmentation during the Mesozoic (Pearson et al., 2013; Herman et al., 2023). This study aims to quantify the magnitude of lithospheric extension associated with the rifting phase, focusing on the geochemical and petrological analysis of mafic volcanic rocks, specifically basalts of the Las Conchas Formation. This unit was emplaced during the active extensional phase and later deformed by compressional tectonics related to Andean orogenesis. The tectonic inversion has obscured the original architecture, rendering traditional structural approaches to estimating extension, such as fault displacement analysis or restoration of balanced cross-sections, largely inapplicable.

Sampling was conducted along the Las Conchas River in the Alemania region. Petrographic analysis revealed porphyritic textures, with phenocrysts of olivine, often altered, clinopyroxene, and plagioclase, as well as mantle xenoliths. We employed a geochemical modelling approach based on the major element composition of basaltic magmas, following the framework established by Langmuir et al., 1992. This model correlates the concentrations of key oxides, Na_2O, FeO, and MgO, with mantle melting parameters such as pressure of initiation and termination of melting, degree of partial melting, and mantle source characteristics.

Major element concentrations were obtained via X-ray fluorescence on glass disks prepared by fusion with lithium tetraborate. The basalts exhibit SiO_2 values ranging from 44–47 wt.%, with Na_2O and K_2O contents between 4–8 wt.%, placing them in the alkaline to transitional basalt field in TAS diagrams. Elevated TiO_2, up to 3 wt.%, and P_2O_5, up to 1 wt.%, levels further support an intraplate context. To control for fractional crystallization and isolate primary melt signatures, compositions were limited to 8 wt.% MgO. Using regression of Na_2O and FeO against MgO content, primary melt compositions were projected onto experimentally derived pressure-dependent melting curves.

The modelled mantle melting path suggests that partial melting commenced at a pressure of ~3.3 GPa, approximately 99 km depth, and terminated at ~3 GPa, approximately 90 km depth, implying a vertical extent of the melting column of ~9 km. This pressure range corresponds to a ~9% reduction in lithospheric thickness, interpreted as the magnitude of extension during rifting. Integrating this with structural reconstructions and regional cross-sections from the Tonco-Amblayo sector (Kortyna et al., 2019) where the current rift width is ~218 km following Andean compression, it is estimated that the Salta Rift attained a pre-inversion width of approximately 300 km. Using the geochemically derived thinning estimate, we infer an original rift width of ~275 km before lithospheric extension, yielding an extensional increase of ~25 km during the active rift phase.

These findings underscore the significance of integrating geochemical proxies with regional tectonic data in reconstructing the kinematic and dynamic evolution of inverted rift basins. The presence of mantle xenoliths, high-MgO primitive basalts, and alkaline geochemical signatures collectively indicate a mantle source with limited crustal interaction, typical of fast magma ascent through thinned lithosphere. Furthermore, the geochemical evidence for relatively shallow decompression melting supports the interpretation of the Salta Rift as a failed rift system that did not progress to oceanic spreading.

References

Herman P., Jara P. & Charrier R. (2023): Journal of South American Earth Sciences, 127, 104425

Kortyna C., DeCelles P. & Carrapa B. (2019): Andean Tectonics, 429–464.

Langmuir C., Klein E. & Terry Plank (1992): Geophysical Monograph Series, 71, 183–280.

Pearson D., Kapp P., DeCelles P., Reiners P., Gehrels G., Ducea M. & Pullen A. (2013): Geosphere, 9(6), 1766–1782.

COUPLED SURFACE TO DEEP EARTH PROCESSES: PERSPECTIVES FROM TOPO-EUROPE WITH AN EMPHASIS ON CLIMATE- AND ENERGY-RELATED SOCIETAL CHALLENGES

Sierd Cloetingh[1]*, Pietro Sternai[2] & TOPO-EUROPE Team
[1] Utrecht University, Department of Earth Sciences, Utrecht, the Netherlands
[2] University of Milan-Bicocca, Department of Earth and Environmental Sciences, Milano, Italy
* E-mail: s.a.p.l.cloetingh@uu.nl

Understanding the interactions between surface and deep Earth processes is important for research in many diverse scientific areas including climate, environment, energy, georesources and biosphere. The TOPO-EUROPE initiative of the International Lithosphere Program serves as a pan-European platform for integrated surface and deep Earth sciences, synergizing observational studies of the Earth structure and fluxes on all spatial and temporal scales with modelling of Earth processes (Cloetingh et al. 2023). This review provides a survey of scientific developments in our quantitative understanding of coupled surface-deep Earth processes achieved through TOPO-EUROPE. The most notable innovations include (1) a process-based understanding of the connection of upper mantle dynamics and absolute plate motion frames; (2) integrated models for sediment source-to-sink dynamics, demonstrating the importance of mass transfer from mountains to basins and from basin to basin; (3) demonstration of the key role of polyphase evolution of sedimentary basins, the impact of pre-rift and pre-orogenic structures, and the evolution of subsequent lithosphere and landscape dynamics; (4) improved conceptual understanding of the temporal evolution from back-arc extension to tectonic inversion and onset of subduction; (5) models to explain the integrated strength of Europe's lithosphere; (6) concepts governing the interplay between thermal upper mantle processes and stress-induced intraplate deformation; (7) constraints on the record of vertical motions from high-resolution data sets obtained from geo-thermochronology for Europe's topographic evolution; (8) recognition and quantifications of the forcing by erosional and/or glacial-interglacial surface mass transfer on the regional magmatism, with major implications for our understanding of the carbon cycle on geological timescales and the emerging field of biogeodynamics; and (9) the transfer of insights obtained on the coupling of deep Earth and surface processes to the domain of geothermal energy exploration.

Concerning the future research agenda of TOPO-EUROPE, we also discuss the rich potential for further advances, multidisciplinary research and community building across many scientific frontiers, including research on the biosphere, climate and energy. These will focus on obtaining a better insight into the initiation and evolution of subduction systems, the role of mantle plumes in continental rifting and (super)continent break-up, and the deformation and tectonic reactivation of cratons; the interaction between geodynamic, surface and climate processes, such as interactions between glaciation, sea level change and deep Earth processes; the sensitivity, tipping points, and spatio-temporal evolution of the interactions between climate and tectonics as well as the role of rock melting and outgassing in affecting such interactions; the emerging field of biogeodynamics, that is the impact of coupled deep Earth – surface processes on the evolution of life on Earth; and tightening the connection between societal challenges regarding renewable georesources, climate change, natural geohazards, and novel process-understanding of the Earth system.

References

Cloetingh S., Sternai P., Koptev A., Eblers T.A., Gerya T., Kovács I., Oerlemans J., Beekman F., Lavallée Y., Dingwell D., Békési E., Porkolás K., Tesauro M., Laveccia A., Botsyun S., Muller V., Roure F., Serpelloni E., Matenco L., Castelltort S., Giovannelli D., Brovarone A.V., Malaspina N., Coletti G., Valla P. & Limberger J. (2023): Global and Planetary Change, 226, 104140

Haq B.U. & Cloetingh S. (2025): Earth-Science Reviews, 267, 105166

TRACES OF MAGMA EVOLUTION RECORDED IN AMPHIBOLE TEXTURES AND COMPOSITIONS: INSIGHTS FROM THE LAST 160,000 YEARS OF CIOMADUL VOLCANO, ROMANIA

Barbara Cserép[1,2]*, Szabolcs Harangi[1,2], Saskia Erdmann[3], Attila Virág[1,2], Máté Szemerédi[2,4] & Réka Lukács[1,2]

[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Institute of Geography and Earth Sciences, Budapest, Hungary

[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[3] Université d'Orléans-CNRS/INSU-ISTO-BRGM, Orléans, France

[4] University of Szeged, Department of Geology, 'Vulcano' Petrology and Geochemistry Research Group, Szeged, Hungary

* E-mail: cserep.barbara@gmail.com

Amphibole is the most common mafic mineral (1–15 vol%) in the products of Ciomadul's volcanic eruptions over the last 160 ka (Eastern Carpathians). It appears in various textural and compositional forms in four distinct types of dacite alongside various mineral assemblages. Products of Epoch 4 eruptions (160–95 ka) include Ciomadul Mic-, and rare Haramul Mic-type rocks, while Epoch 5 eruptions (55–30 ka) produced Tuşnad-, and Bixad-type dacites. Amphibole is the only mineral stable in all erupted magmas and magmatic environments associated with the four studied dacite types, making it an excellent recorder of the magmatic system and the processes leading to different eruption episodes.

We have studied 481 samples from eruptive episodes 4/1, 4/2, 4/3, 5/1, and 5/2 (Molnár et al., 2019), and from all four studied dacite types, to characterise both older, dome-forming eruptions and younger, predominantly explosive eruptions occasionally interrupted by effusive activity. Amphibole was investigated using hand lenses, polarized-light microscopy, back-scattered electron imaging, electron microprobe (EPMA) for major elements, and laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) for trace-element quantification and mapping.

Amphibole crystals classify as magnesio-hornblende and pargasite/magnesio-hastingsite (Hawthorne et al., 2012). They exhibit a wide compositional range in major element concentrations (SiO_2: 39.5–51.0 wt%; TiO_2: 0.4–3.0 wt%; Al_2O_3: 5.5–15.0 wt%; FeO: 3.5–19.0 wt%; MgO: 9.5–21.0 wt%; CaO: 10.5–12.0 wt%; Na_2O: 1.0–2.5 wt%; K_2O: 0.5–1.5 wt%) and trace element concentrations (e.g., Ni: 13–2500 ppm; Cr: 5–8700 ppm; Sr: 50–950 ppm; ΣREE: 50–500 ppm). Statistical analyses identified six main amphibole groups, corresponding to distinct magmatic environments (two crystal mush, three recharge, and one hybrid type), supported by textural and mineral-assemblage evidence. These groups can form distinct zones within individual crystals, with sharp boundaries evident on trace element maps. Major element compositions primarily differ in Na_2O, FeO, and MnO ± SiO_2 (~74% variance), yet also in TiO_2, Na_2O, Al_2O_3, and MgO (~20% variance). Trace element variations are dominated by Cr, Ni, Ba, Sr, and Nd (~61% variance) and La, Pr, Sr, and Gd (~23% variance). Recharge domains show complex, oscillatory zoning in Cr, Ni, and Zr, while crystal mush domains predominantly display disrupted, patchy resorption textures for most elements, and hybrid zones show slight patchiness. The six magmatic environments form part of an open, transcrustal magmatic system, which allowed crystal transfer and interaction among distinct melts and magmatic environments over time.

The two crystal mush amphibole types are present in all eruption products (~10–82% and 5–26% of all amphibole, respectively). Recharge amphiboles occur in all but the rare Haramul Mic-type eruption products in various amounts (~5–30% of amphibole), showing a clear compositional shift from early to late eruption products, pointing towards a significant transformation in magma supply from the source and/or deep fractionation. Hybridization likely occured when crystal mush magma made up a small proportion relative to recharge magma, as recorded by relatively rare (<20%) crystal mush amphibole in Bixad-type samples.

References

Hawthorne F.C., Oberti R., Harlow G.E., Maresch W.V., Martin R.F., Schumacher J.C. & Welch M.D. (2012): American Mineralogist, 97, 2031–2048.

Molnár K., Lukács R., Dunkl I., Schmitt A.K., Kiss B., Seghedi I., Szepesi J. & Harangi S. (2019): Journal of Volcanology and Geothermal Research, 373, 133–147.

SAMPLING STRATEGY AND QUANTIFICATION OF EXTREMELY INHOMOGENEOUS FOCUSED AND DIFFUSE CO_2 EFFLUX

István Csige[1]*, Sándor Gyila[2]
[1] HUN-REN Institute for Nuclear Research, Debrecen, Hungary
[2] Dr. Benedek Géza Hospital of Cardiology, RO-525200, Covasna, Romania
* E-mail: csige.istvan@atomki.hu

Significantly enhanced carbon dioxide efflux on soil surfaces, often related to post-volcanic activity, can be a potential source of direct life threating risk but may also be used as a curative gas in natural mofettes treating patients suffering from vasocontraction, for example. The aerial distribution of the flux of CO_2 on soil surface, however is often highly variable. Earlier we have found that the relative variability of the measured flux values does not depend on the spatial resolution of the sampling points ranging from 10 meters to down to 0.1 meter. This makes it difficult to design effective sampling strategy when the goal is to determine areal average flux, for example.

In this work, we measured the ground surface flux density of carbon dioxide gas in an area where we were searching for focused degassing vents and aimed to determine the gas yield over a well defined area. We have designed a hierarchically structured sampling strategy starting large scale (6 meter resolution) uniformly distributed sampling followed by ever refined sampling density down to 0.1 m resolution where measured flux values were found significantly higher than biological background of about 1 g/(m^2 h). We have found that the highest values were about 2 orders of magnitude higher than the background but the areal extension of these extremes was limited to a few dm^2. We called these vents focused degassing while the degassing in their vicinity as diffuse degassing. Fig. 1 shows the spatial distribution of the sampling points and also the flux obtained by kriging.

For quantification of the total efflux in a well defined area, we used a very simple approach. Scanning the area of interest with a small (0.1 dm^2) surface element we first searched for the nearest measuring site, and then summed up the elementary fluxes to obtain the total flux. We have found that the contribution of the focused and the diffuse component to the total flux is in the same order. We have concluded that without this hierarchically refining sampling strategy focused degassing spots would easily be ignored.

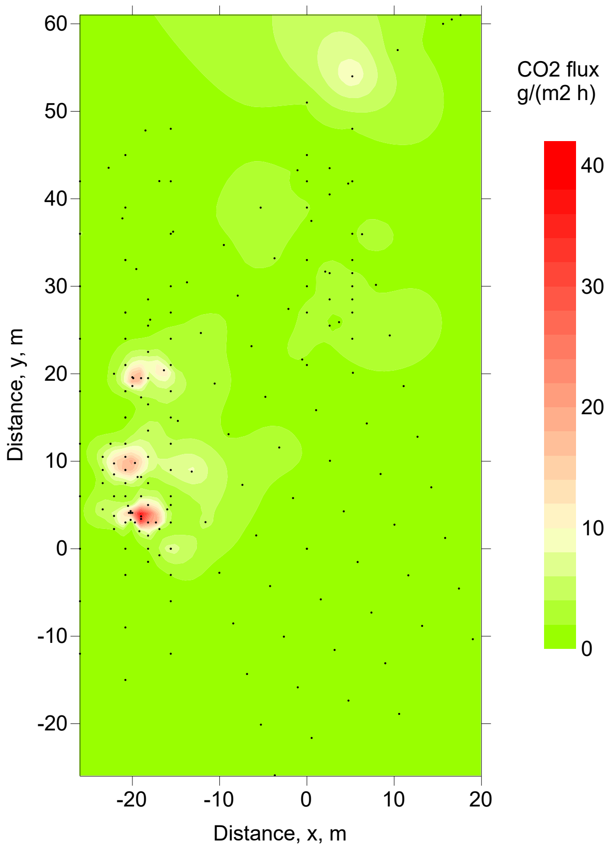


Figure 1. *Spatial distribution of sampling points and CO2 flux in a model area.*

PRELIMINARY RESULTS OF MONITORING INVESTIGATIONS OF THE SZENT ISTVÁN CAVE, BÜKK MOUNTAINS, HUNGARY

György Czuppon[1], Laura Ladics[2], Mihály Braun[3], Lóránt Biró[4] & Erika Kereskényi[5,6]*

[1] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[2] Eötvös Loránd University, Department of Environmental and Landscape Geography, Budapest, Hungary

[3] HUN-REN Institute for Nuclear Research, Debrecen, Hungary

[4] Budapest University of Economics and Business, Budapest, Hungary

[5] Bükk Region UNESCO Global Geopark, Bükk National Park Directorate, Eger

[6] Hungarian National Museum, National Archaeological Institute, Budapest, Hungary

* E-mail: kereskenyierika@yahoo.com

Cave monitoring investigations commenced in September 2024 at the Szent István Cave (Bükk Mountains, NE-Hungary). The primary objective of the monitoring is to provide information about the factors influencing the carbonate precipitation and its chemical and isotopic composition. In the context of show caves, this monitoring work may also yield novel insights into the direct or indirect effects of daily tours on the cave environment.

Temperature loggers were deployed at four distinct locations within the cave: the *Great Hall*, *Tordai Gorge*, *Stage Hall*, and *Black Hall.* These sites are also affected by varying degrees of human impact resulting from daily tours. The impact of tourist groups is clearly evident in the temperature curves: small sudden spikes indicate these events. Besides of these small spikes, the temperature in Great Hall, Tordai Gorge and Black Hall is very stable. The Great Hall behaves differently, as it is located closest to the entrance, so changes in the outside temperature have an effect here (albeit to a lesser extent).

In addition to temperature measurements, a CO_2 logger was also installed in the *Black Hall* to investigate the cave's annual ventilation patterns and the impact of tourism on cave air quality. Preliminary results indicate that CO_2 concentrations were highest between September and November 2024, reaching around 3200 ppm. Weekend events in the *Black Hall* during the winter months significantly elevated CO_2 levels, with a prolonged recovery period of 2-5 days for concentrations to return to previous levels. After winter, CO_2 concentrations did not exhibit significant fluctuations and reacted only moderately to visitor numbers. Besides the obvious effect of visitors on CO_2 concentration, the current data suggest that the CO_2 trend observed is consistent with some other caves (higher summer and lower winter values).

Drip intensity is recorded at the *Hall of Columns* and the *Tordai Gorge*. The drip point in the *Hall of Columns* exhibits greater variability, - which appears to follow the precipitation events -, compared to *Tordai Gorge.* These observations suggest stronger and more direct water infiltration in the epikarst above the *Hall of Columns*.

Drip waters are collected in the *Tordai Gorge, Spirit of the Cave*, *Hall of Columns, Stage Hall*, and the *Black Hall* for H-O stable isotope analyses. The stable isotope composition of drip waters shows relatively small variability compared to the observed variability in precipitation stable isotope composition. This observation is particularly true for the *Spirit of the Cave* and the *Black Hall*. Although a full year of data is not yet available, it appears that the drip water collected at these points has a relatively long residence time. It is noteworthy that their stable isotope compositions are the most negative. It is possible that winter precipitation contributes a larger proportion of the infiltrating water at these points. The observed variability at other points may indicate shorter residence times.

Glass plates have been placed at five active drip points (*Tordai Gorge, Spirit of the Cave, Hall of Columns, Stage Hall*, *Black Hall*) and are exchanged seasonally to determine the mineralogical, chemical and isotopic composition of the precipitated carbonates.

This research has been supported by the UNESCO ABRDN grant awarded to the Bükk Region UNESCO Global Geopark and National Research, Development and Innovation Office, Hungary (FK 138626). We express our gratitude to Gergely Ferenczy and the Bükk National Park Directorate.

PRELIMINARY RESULTS OF RECENTLY GROWING SPELEOTHEM FROM THE SZENT ISTVÁN CAVE, BÜKK MOUNTAINS, HUNGARY

György Czuppon[1]*, Laura Ladics[2], Mihály Molnár[3], Mihály Braun[4], Lóránt Biró[5] & Erika Kereskényi[6,7]

[1] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[2] Eötvös Loránd University, Department of Environmental and Landscape Geography, Budapest, Hungary

[3] HUN-REN Institute for Nuclear Research, International Radiocarbon AMS Competence and Training (INTERACT) Center, Debrecen, Hungary

[4] HUN-REN Institute for Nuclear Research, Debrecen, Hungary

[5] Budapest University of Economics and Business, Budapest, Hungary

[6] Bükk Region UNESCO Global Geopark, Bükk National Park Directorate, Eger

[7] Hungarian National Museum, National Archaeological Institute, Budapest, Hungary

* E-mail: czuppon.gyorgy@csfk.org

Paleoclimatological and comprehensive cave monitoring investigations commenced in September 2024 at the Szent István Cave, which is located in the central part of the Bükk Mountains. The primary objective was to reconstruct past climate and environmental conditions utilizing speleothems which were growing on artificial surfaces.

Several sites were selected for drilling speleothems: Tordai-hasadék, Oszlopok-csarnoka and Meseország and were collected in December 2024. Construction of the artificial surfaces was commenced in 1928 and completed in 1931; meaning these speleothems could potentially cover almost the last 100 years. Based on their inner structure and petrographic features only three speleothem cores seemed to be appropriate for further investigation. Two speleothems (SZT-CSP1 and SZT-CSP2) were collected in Oszlopok-csarnoka and one in Meseország. These speleothem cores were sampled for carbon and oxygen isotope analyses: the SZT-CSP1 and SZT-CSP4 cores were sampled at relatively low resolution (approximately 1 mm), while the SZT-CSP2 was sampled at high resolution (approximately 0.1 mm). The carbon and oxygen isotope values of all speleothems cover a relatively large range (~3 ‰). This variability is likely related to past climate and environmental changes (e.g., amount and seasonality of precipitation, temperature) and changes in cave management (e.g., construction, opening/closing passages and gates).

This research has been supported by the UNESCO ABRDN grant awarded to the Bükk Region UNESCO Global Geopark and National Research, Development and Innovation Office, Hungary (FK 138626). We express our gratitude to Gergely Ferenczy and the Bükk National Park Directorate.

CAVE MONITORING IN HUNGARY WITH SPECIAL FOCUS ON MG AND CA ISOTOPES OF DRIP WATER AND CARBONATE PRECIPITATES

György Czuppon[1]*, László Palcsu[2], Mihály Braun[2], Lóránt Biró[3], Anikó Horváth[2], Stieber József[4], Yuefeng Liu[1] & Péter Dobosy[5]

[1] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[2] HUN-REN Institute for Nuclear Research, Isotope Climatology and Environmental Research Centre (ICER), Debrecen, Hungary

[3] Budapest University of Economics and Business, Budapest, Hungary

[4] Stieber Environmental Ltd., Budapest, Hungary

[5] HUN-REN Centre for Ecological Research, Institute of Aquatic Ecology, Budapest, Hungary

* E-mail: czuppon@geochem.hu

Speleothems, which grow in caves, are considered to be among the most important climate archives in continental areas. However, caves are complex environments. Therefore, to use speleothems to reconstruct past climate and environmental changes, it is necessary to understand the environmental and hydrological processes that determine the physicochemical conditions of carbonate precipitation and hence speleothem formation. Therefore, cave monitoring researches have been conducting in three caves in Hungary since 2013: Csodabogyós Cave in Keszthely Mts (West Hungary), Béke and Baradla caves in Aggtelek (Northeast Hungary). To expand the set of speleothem-based proxies the monitoring activities, which included monitoring of climatological parameters (e.g., temperature, CO2) measured inside and outside the caves, drip rate, the chemical, trace element, stable hydrogen and oxygen isotopic compositions of drip waters, stable carbon and oxygen isotope analyses of newly formed carbonates, was complemented with calcium, magnesium and strontium isotope measurements of drip waters and newly formed carbonates since 2022.

Climatological investigation revealed seasonality in CO_2 concentration related to outside temperature variation indicating variable ventilation regime in the studied caves. The comparison of the stable isotope composition of the drip waters and the amount-weighted precipitation indicated that the epikarst above the studied sites is generally well mixed and the dominant infiltration takes place during the winter half year. Moreover, the long-term monitoring of the stable isotope composition of drip water in Baradla Cave and the precipitation indicates that slight changes in the precipitation over the years can be reflected in the composition of the drip waters. Although the seasonal isotopic signal observed in precipitation is generally not transmitted to drip water, inter-annual variability can be recorded in drip water and hence in the precipitating carbonate (e.g., speleothem).

The Mg isotope analyses of the drip water revealed systematic differences among the caves. In addition, the prelimary results suggest that the isotopic composition variability depends on the hydrological conditions.

The research was financially supported by the National Research, Development and Innovation Office, Hungary (OTKA FK 138626). We are also grateful for the support and permission of the Aggtelek National Park Directorate.

PCA, CLUSTERING, AND GEO-AI-BASED SEDIMENTOLOGICAL AND PETROGRAPHIC ANALYSIS FOR DEPOSITIONAL ENVIRONMENT INTERPRETATION OF PALEOZOIC–MESOZOIC SEDIMENTARY SEQUENCES: EVIDENCE FROM WADI HALFA, NORTHERN SUDAN

Abazar Mohamed Ahmed Daoud[1,2]*, Musaab Adam Ahmed Mohamed[3,4], Mohammed Noor Mohammednoor Hassan[1,5] & Péter Rózsa[1]
[1] University of Debrecen, Department of Mineralogy and Geology, Debrecen, Hungary
[2] Red Sea University, Faculty of Earth Sciences, Port Sudan, Sudan
[3] University of Miskolc, Faculty of Earth and Environmental Science and Engineering, Miskolc, Hungary
[4] University of Bahri, College of Petroleum Geology and Minerals, Khartoum, Sudan
[5] Al Neelain University, Faculty of Petroleum and Minerals, Sudan
* E-mail: abazar.daoud@science.unideb.hu

The Nubian Sandstone Formation is one of the most well-known sedimentary formations in the world, yet it still poses challenges in terms of accurate identification and depositional environment. In the present study, the integration of sedimentological and petrographical datasets, combined with advanced statistical analyses and machine learning algorithms, has been employed to successfully discriminate the depositional environments and reconstruct the paleogeographic evolution of the Nubian Sandstone Formation (NSF) in northeastern Sudan, with a particular focus on the Wadi Halfa Oolitic Ironstone Formation (WHOI). Principal Component Analysis (PCA), cluster analysis, Analysis of Variance (ANOVA), Tukey's Honestly Significant Difference (HSD), Multidimensional Scaling (MDS), and GeoAI unveil significant variations in deposition environment interpretations. PCA exhibits different patterns in sediment composition, with clear separation of samples into fluvial, deltaic, and marine environments based on the first four principal components. Cluster analysis identified three distinct groups: Cluster 1, characterized by high gravel content, indicative of fluvial sediments; Cluster 2, dominated by sand, reflecting deltaic deposits; and Cluster 3, enriched in silt, clay, and fossil evidence, representing shallow marine sediments. These statistical findings are strongly corroborated by detailed studies of vertical lithofacies, contributing a powerful foundation for interpreting sedimentary environments and their associated depositional processes.

Facies observed during the detailed fieldwork include trough and planar cross-bedded sandstone, fine and massive mudstone facies, massive conglomerate facies, and oolitic ironstone facies. Petrographic analyses reveal that the high maturity of quartzarenite reflects extended sediment transport and reworking under warm, humid climatic conditions, indicative of a stable tectonic setting. The presence of kaolinite and oolitic ironstone further supports extensive chemical weathering and sedimentation in tropical environments, where intense leaching processes existed. Additionally, hematite, identified as the dominant cementing material in most sandstone samples, signifies deposition under oxidizing conditions.

ON THE ORIGIN OF THE MYSTERIOUS CARBONADO DIAMOND

Attila Demény[1]*, Péter Németh[1] & Francisco Valdir Silveira[2]

[1] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[2] Geological Survey of Brazil, Brasilia, Brazil

* E-mail: demeny.attila@csfk.hun-ren.hu

Carbonado diamonds consist of polycrystalline aggregates of micron-sized crystals. Yet, unlike gem or polycrystalline diamonds found in kimberlites or lamproites, which are proven to be of mantle origin, carbonado (i) contains many mm-sized pores filled with secondary minerals; (ii) its stable carbon isotope composition falls in a very negative, narrow range ($\delta^{13}C$ = –32 to –24 ‰); (iii) mantle-specific minerals (e.g., garnet, spinel, pyrrhotite) are missing; (iv) carbonado is found in a delimited area in the alluvial sediments of Brazil and Central Africa; and (v) the surface of the grains shows phenomena indicative of melting (see the review of Haggerty, 2017 and references therein). The melting phenomenon was one of his most important arguments in support of an extraterrestrial origin.

One of the most intriguing features is the glassy, melting-looking surface of the irregular carbonado fragments. If it is really related to melting of diamond, then impact-related frictional melting should be taken into consideration. In order to determine the processes that lead to the glassy surface formation, a set of 40 samples collected from the Tombador conglomerate of the Chapata Diamantina area of Brazil were first inspected under a binocular microscope to select samples with the most developed melting-looking surfaces resembling the "melt marble" illustrated by Haggerty (2017). The selected samples were analysed by stable carbon isotope measurements, scanning electron microscopy (SEM), transmission electron microscopy (TEM), and X-ray computed tomography (CT) to (i) determine the origin of the glassy "patina" ("fusion crust"?) and (ii) create a general model that would explain the present study and previously published observations together.

The studied samples are carbonado diamonds sensu stricto, i.e., black, microcrystalline grains characterized by high porosity of empty pores and pores filled with florencite-kaolinite mixture, bright red and green cathodoluminescence (CL), and low carbon isotope values (between –24.8 and –27.4 ‰). The carbonado grains are all characterized by smooth, glassy surface. The glassy surface is not associated with crystallinity or textural change in the diamond. TEM and CT analyses indicate a complex plastic and brittle deformation history. Some of the carbonados are encrusted by nanocrystalline anatase, which preserved euhedral diamond crystals. The nanocrystalline anatase formation is presumably related to low-temperature alteration of a Ti-rich volcanic rock that hosted diamond fragments. The smooth surface of anatase and its continuous contact with the glassy diamond surface suggest that the smoothing event postdated the anatase formation. The high-temperature melting ("fusion crust" formation) event can be excluded.

Impact-induced subduction of Archaean organic matter, fast diamond formation, break-up and transport to the surface by a volcanic event (eruption of kimberlite-like magma) would be consistent with the observations of the present study as well as with published studies. The rapid subduction and ejection may explain the porous diamond formation, the occasional and non-systematic mixing with mantle material, the lack of graphite, and the diamond deformation features. Interaction with REE- and alkali-rich fluids, nanocrystalline anatase formation, followed by resorption by metamorphic fluids may be consistent with interactions with the mobilized volcanic materials and metamorphic fluids.

The study was supported by the National Research, Development and Innovation Office (No. 149522).

References

Haggerty S. (2017): Gems and Gemology, 53, 168–179.

MAGMATIC ARCHITECTURE OF CONTINENTAL CRUST IN CONVERGENT SETTINGS

Mihai Ducea[1,2]*
[1] University of Bucharest, Faculty of Geology and Geophysics, Bucharest, Romania
[2] University of Arizona, Department of Geosciences, Tucson, USA
* E-mail: mihai@ducea.com

Most convergent margins have associated magmatism on their upper plates. When the upper plate is continental, there are three types of magmatic products: subduction related frontal arcs, backarc extension magmatism, plateau magmatism and collisional arcs. There are also some convergent margins that are amagmatic. The great majority of these products are calc-alkaline, the thicker the upper plate, the richer in silica and alkalis these rocks are. Depletions in high field strength trace elements is a signature of these types of magmas throughout the history of continents. The most likely cause of that elemental depletion is the formation of amphibole and rutile as arc magmatic cumulate minerals, although other sequesters of those elements may play a role (carbonates, ilmenite, etc.)

I will review the most important observations we have for each setting, going through evidence from classic crustal sections of defunct arcs and modern volcanic equivalents. The salient observation that does not always get full credit in the community is that most influx of magma from the mantle wedge is basaltic. Magmatic diversification toward higher silica is an upper plate, lower crustal phenomenon, not something derived from slabs or the mantle, despite obvious fluxes of mass from the slabs. The other important finding after half a century of modern studies of arc magmas is that not all basaltic mantle-derived melt (either from peridotites or pyroxenites) is generated in the asthenosphere (the so called "mantle wedge"), but a sizable percent comes from melting the subcontinental mantle lithosphere. We have never been in a more critical need for a simple elegant mechanism for making arc magmas, as we realize that water-fluxed melting of mantle wedges is a good conversation starter but not a fit-all model by any means. However, we do not have such a quantitative model at this point, certainly not one to be accepted by the community.

Frontal arcs are decidedly different from back arc basins, wherever they form, as well as from plateau settings, when upper plates are under convergence. Chemistry to some extent, but principally the overall crustal architecture of magmatic systems could not be more distinct in frontal arcs from backarcs and plateaus. That should allow us to distinguish subduction magmatism from backarc zones or plateau products in deep time, which has not been rigorously attempted so far. Collisional (sometimes referred to as "post-collisional") magmatism is remarkably similar to frontal arcs of subduction zones, except it typically has an order of magnitude lower flux, and is more potassic and shorter lived. However, what remains critical to any discussion on collisional magmas, is the fact that andesites with biotite, amphibole and pyroxene, as well as more silicic dacites, are the signature product of collisional belts, and they are identical to subduction settings. Amagmatic convergent zones are an anomaly, but they are nevertheless part of the story. While classically attributed to zones of flat slabs, these regions may also owe their lack of magmatism to unusually depleted mantle regions and presence of melt retardants, including carbonate subduction and its diapirism into the wedge.

ADAKITE-LIKE AND NORMAL CALC-ALKALINE SUITES FROM THE SOUTH APUSENI MOUNTAINS: A PHENOCRYST STORY

Vlad-Victor Ene[1,2]*, Daniel J. Smith[3], Kristina Mervič[4] & Martin Šala[4]

[1] University of Bucharest, Department of Geology, Bucharest, Romania

[2] Romanian Academy, Institute of Geodynamics Sabba S. Ştefanescu, Bucharest, Romania

[3] University of Leicester, School of Geography, Geology and the Environment, Leicester, United Kingdom

[4] National Institute of Chemistry, Ljubljana, Slovenia

* E-mail: vlad-victor.ene@g.unibuc.ro

Neogene magmatism in the South Apuseni Mountains, hosting numerous Au ± Te ore deposits and active between ca. 14 Ma and 7 Ma (Ene et al., 2024), was generated in an extensional setting as the underlying Dacia-Tisza crustal block was undergoing eastward-extension and rotation (e.g., Seghedi et al., 2022). Most samples are intermediate, porphyritic, and contain phenocrysts of plagioclase, amphibole, and clinopyroxene. Furthermore, they exhibit geochemical characteristics associated with arc magmatism, such as positive anomalies in LILEs, LREEs, and Pb and negative anomalies in Nb, Ta, and Ti. In addition, rocks with high Sr/Y values, similar to rocks referred to as adakites, have also been described. Hypotheses regarding the formation of both normal calc-alkaline and high Sr/Y rocks range from melting of a heterogeneous SCLM that was metasomatized during previous Mesozoic magmatic events (Roşu et al., 2004; Harris et al., 2013) to melting of delaminated, eclogitized lower crust (Seghedi et al., 2007) or mixing in various proportions between mantle and crustal sources (Seghedi et al., 2022).

New whole-rock geochemical and isotopic data allow a better reconstruction of the evolutionary history of the Neogene magmatism in the South Apuseni Mountains. Isotopically, most samples plot between MORB and more evolved crustal lithologies in the area. High-Sr/Y samples tend to exhibit more juvenile compositions; however, there are calc-alkaline suites (e.g., from the western South Apuseni Mountains) that exhibit similar isotopic Sr, Nd, and Hf values, indicating possible significant heterogeneities in the source.

Geochemical mapping using a LA-TOF-ICP-MS system was undertaken on plagioclase, amphibole, and clinopyroxene phenocrysts from adakite-like and normal calc-alkaline suites to better constrain the magmatic processes leading to both high Sr/Y and low Sr/Y rocks. Intricate zonation patterns can be observed in all phenocrysts, especially in elements indicating mafic recharge such as Cr, Ni, or Sc. In addition, positive correlations between Cr and Sr can be observed in some amphibole and plagioclase phenocrysts, suggesting recharge with a Sr enriched melt. The Sr values of the feldspar phenocrysts positively correlate with whole-rock Sr concentrations. Modelling the composition of melts in equilibrium with feldspar crystals, using the equations of Blundy & Wood (1991), reveals contrasting compositions for similar An values, indicating feldspar as an early high-temperature phase, crystallizing from mafic melts with different Sr compositions. This suggests that the high Sr values might be inherited from source.

These findings underscore the petrogenetic complexity of Neogene magmatism in the South Apuseni Mountains and provide new constraints on magma genesis in post-collisional settings.

References

Blundy J.D. & Wood B.J. (1991): Geochimica et Cosmochimica Acta, 55, 193–209.

Ene V.V., Tapster S., Smith D.J., Panaiotu C., Roșu E., Naden J. & Munteanu M. (2024): Journal of the Geological Society, 181(2), jgs2023-048

Harris C., Pettke T., Heinrich C.A., Roșu E., Woodland S. & Fry B. (2013): Earth and Planetary Science Letters, 366, 122–136.

Roşu E., Seghedi I., Downes H., Alderton D., Szakacs A., Pécskay Z., Panaiotu C., Panaiotu C. & Nedelcu L. (2004): Schweizerische Mineralogische und Petrographische Mitteilungen, 84, 153–172.

Seghedi I., Bojar A.-V., Downes H., Roşu E., Tonarini S. & Mason P.R.D. (2007): Chemical Geology, 245, 70–88.

Seghedi I., Ntaflos T., Pécskay Z., Panaiotu C., Mirea V. & Downes H. (2022): International Geology Review 64(13), 1885–1911.

Migration of deformation, basin subsidence, magmatism in the extensional Pannonian Basin: good fit between numerical models and observations

László Fodor[1,2]*, Attila Balázs[3], Éva Oravecz[2,3], Szabolcs Harangi[4,5], Sierd Cloetingh[1,6], Taras Gerya[3] & Réka Lukács[4,5]

[1] HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary
[2] Eötvös Loránd University, Department of Geology, Budapest, Hungary
[3] ETH Zürich, Institute of Geophysics, Zürich, Switzerland
[4] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[5] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[6] Utrecht University, Department of Earth Sciences, Utrecht, the Netherlands
* E-mail: fodor.laszlo@epss.hun-ren.hu

1. Introduction

Numerical models are essential tools for investigating a variety of Earth phenomena, providing insights into the role of different surface to deep Earth processes. As with many laboratory approaches, the effectiveness of the models can be assessed by comparing their results with natural case studies of the same phenomenon, which helps to constrain the large number of model parameters.

This presentation will take the example of the Pannonian Basin system having been formed within the Alpine–Carpathian–Dinaric orogenic belt, where geological data are abundant, and the temporal resolution of basin evolution including magmatic events are very good and in the range of the numerical modelling results.

2. Methods

We used fully coupled 3D petrological–thermo-mechanical and surface processes numerical models (I3ELVIS-FDSPM numerical code, Gerya & Yuen, 2007; Munch et al., 2022; Balázs et al., 2023; Oravecz et al., 2024) to simulate continental rifting and to shed light on the temporal evolution of the entire rift system. A hydrated weak zone is implemented in the mantle lithosphere to simulate an inherited suture zone (Fig. 1). We used orthogonal model set up when the angle between the weak zone and the extension-perpendicular direction is zero. A 50 km wide colder and thus stronger domain is defined on the left and right sides of the model, which prevents deformation localization at the lateral model boundaries during rift initiation. These colder domains were cropped before visualization and interpretation. (after Oravecz, 2024; Oravecz et al., 2025).

We compared numerical modelling results to variable data sets depicting the age of the oldest sediments in different sub-basins, the activity of major faults, and the onset of rhyolitic and locally andesitic magmatism. Data are derived from a great number of publications, including but not restricted to Balázs et al. (2016); Fodor et al. (2021); Lukács (2024); Lukács et al. (2024); Šujan et al. (2021); Tari (1994); Tari et al. (1999).

3. Results

3.1. Results of the numerical modelling

Orthogonal rift evolution in numerical models is depicted after Oravecz et al. (2025). a) Rift initiation corresponds to the extensional reactivation of the pre-existing suture zone inherited from a previous orogenic cycle, leading to the development of the first syn-rift normal fault in the crust (Fig. 1a). Rapid thinning of the lithosphere above the rising asthenospheric upwelling is associated with the migration of deformation in the crust. The second set of conjugate normal faults forms the other margin of the developing rift system (Fig. 1b). The crustal deformation migrates towards the basin centre, e.g., backward toward the initial basin margin, successively forming new syn-rift faults and depocenters, while the active deformation ceases in the older marginal depocenters (Fig. 1c). Deformation of the lower crust is characterized by ductile flow, while crustal melting is observed from 5.6 Myr (inset I Fig. 1c). During the final step, the basin migration is oriented away from the basin centre, toward the opposite margin of the basin (location of basin subsidence of step 2), and even beyond. The basin centre subsidence remains active. Necking of the continental lithosphere, and decompressional melting of the mantle occur from 7.4 Myr (Fig. 1d).

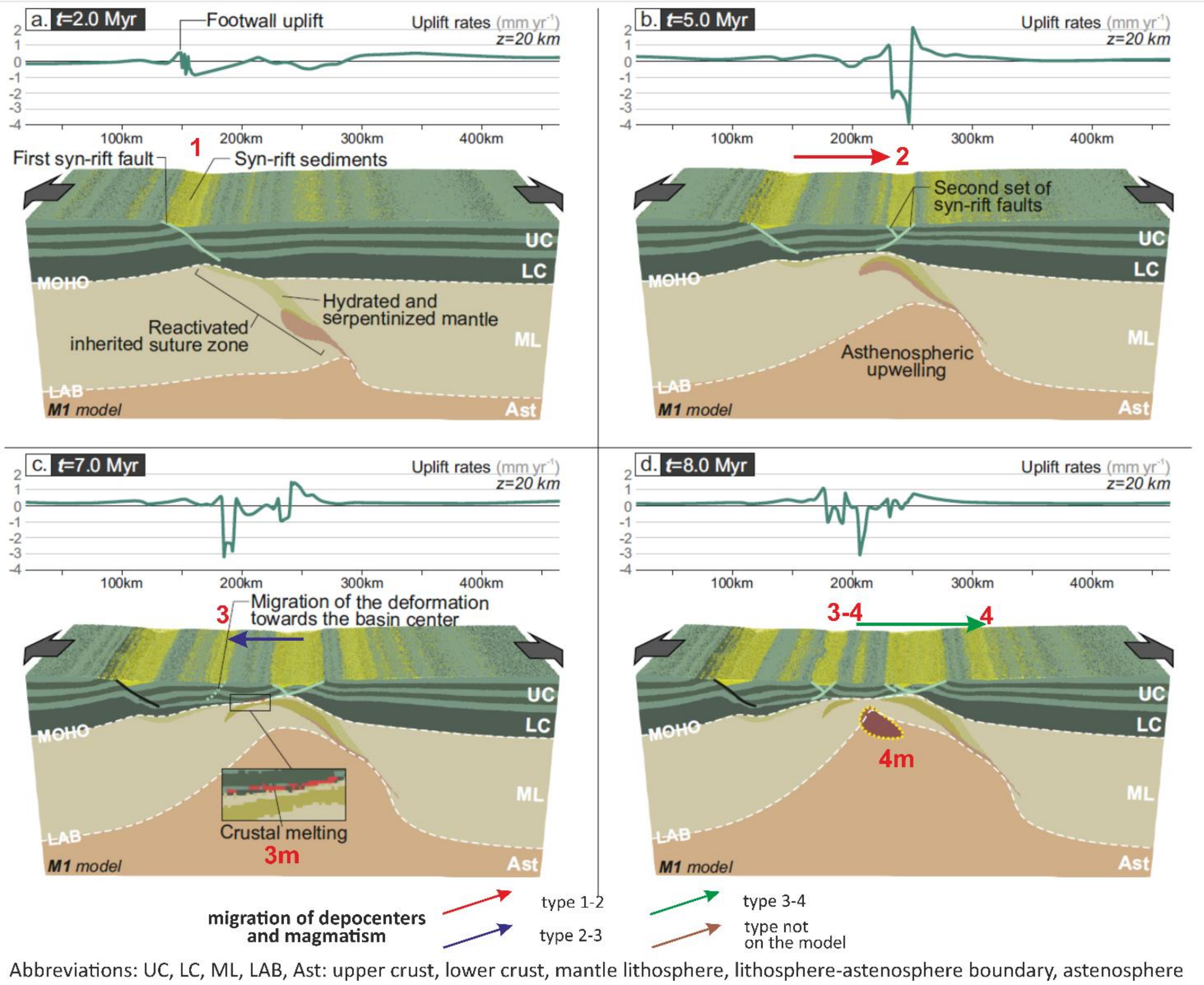


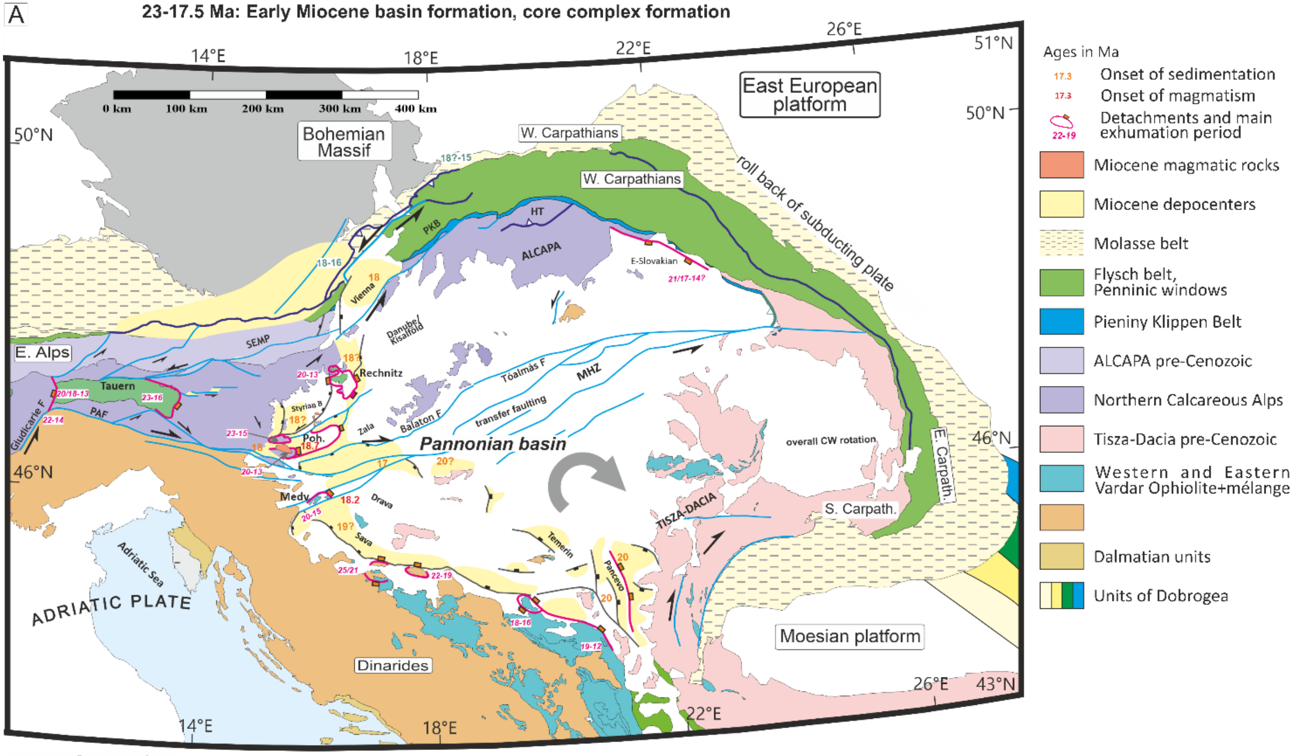
Figure 1. *Selected steps in modelling results highlighting the main phases of depocenter migration and change in magmatism. The letter t indicates timing after the onset of extension. Note locations of uplift and subsidence (negative uplift) indicated by green line above the models.*

3.2. Comparison of numerical modelling results and basin evolution steps of the Pannonian basin system

In the case of the Pannonian basin system, the extensional deformation starts than migrates from the (western) basin margins, from inherited lithospheric weakness zones towards the basin centre (Fig. 2a). Basin migration first occurs in the supra-detachment basins (M1 on Fig. 2b). An early jump from the western margin toward the opposite basin part is also present (M2 on Fig. 2b, M4 on Fig. 2c) although the timing seems to be retarded in the Tisza-Dacia unit. This explains the fast subsidence of the Etes graben and Nógrád-Novohrad small basins during the Karpatian; a fact which was not explained in earlier models. This is followed by a second jump of basin formation toward the western basin part, between the first and second generations of basins (M1 on Fig. 2c, M1 on Fig. 2d), again with a slight delay in the southern unit. The final migration of basins was oriented toward the back-stepping subduction below the Northeastern Carpathians (Fig. 2d). This is well shown by migration of the basin within the Western Carpathians from the Blatné to the Turiec basins which is parallel to the migration of the external thrust front.

The migration of basin formation shows remarkably similar migration to the magmatic activity. This started with granodioritic–dacitic products around 18.7 Ma along the western basin margin (Fig. 2a), then jumped toward the opposite basin part (Nógrád-Novohrad area and Bükk Forelands) around 17.3–16.8 Ma (M3 on Fig. 2b). The magma generation in the lower crust and mantle (by decompressional melting) is predicted by numerical models (Fig. 1c). During the third stage, the volcanism stepped back toward the western basin part around 15.3 Ma with a change toward andesitic volcanism (M1 on Fig. 2c). Geochemical characteristics indicate increasing mantle component in the melts during the continuing extension until ca. 11 Ma (M4 on Fig. 2d). This is due to subduction roll back and lithospheric thinning (Lukács et al., 2024).

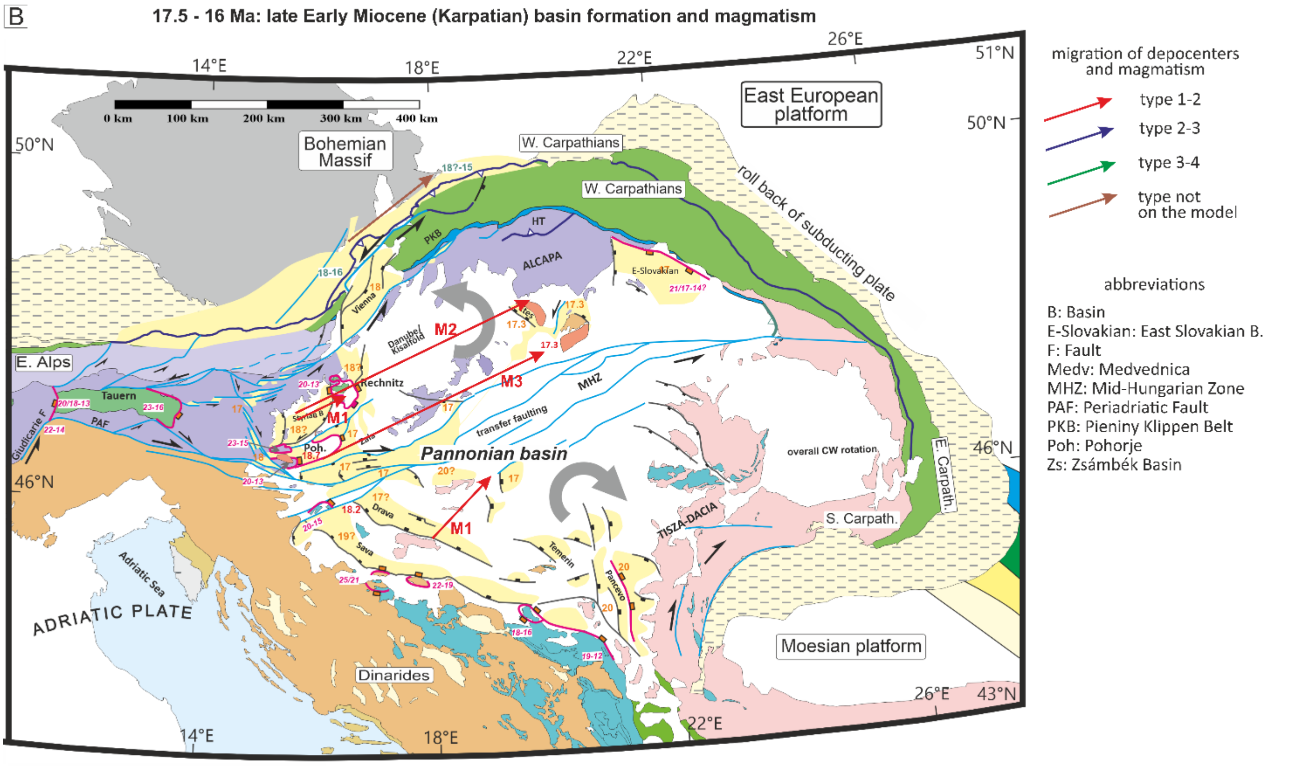
A 23-17.5 Ma: Early Miocene basin formation, core complex formation



Onset of extension:

- Core complex formation along the western and southern (Dinaridic) margin along inherited weakness zones (e.g., Sava suture)
- Supradetachment basins
- Magmatism in the Pohorje and in Croatia

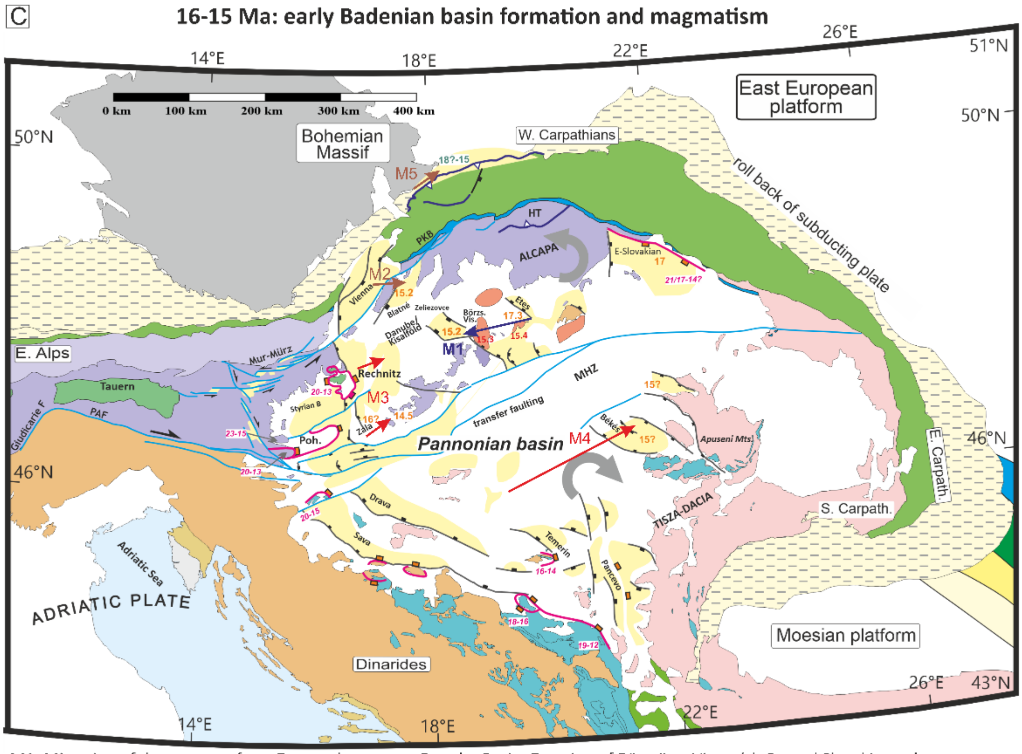
B 17.5 - 16 Ma: late Early Miocene (Karpatian) basin formation and magmatism



Continuing core complex formation

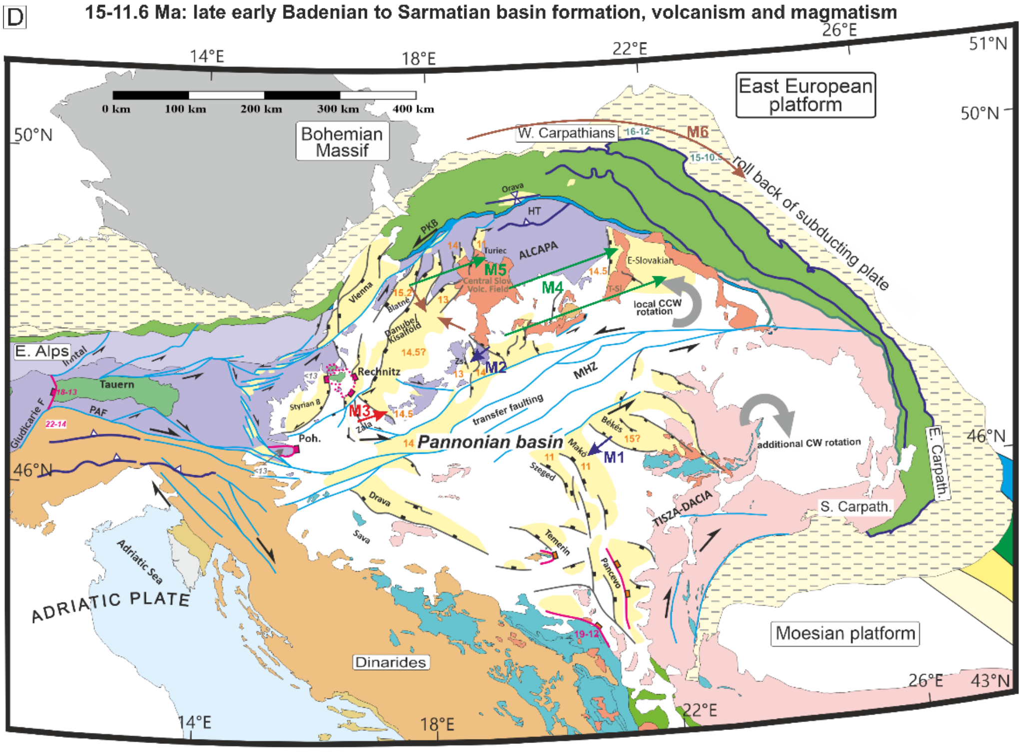
- M1: Migration of supradetachment basins toward the hanging wall (both in ALCAPA and Tisza-Dacia)
- M2: Jump of depocentres to central-eastern ALCAPA (Etes and Nógrád sub-basins)
- M3: Jump of magmatism from the south-western to central areas

C 16-15 Ma: early Badenian basin formation and magmatism



M1: Migration of depocentres from Etes to the eastern Danube Basin; Eruption of Börzsöny, Visegrád, Central Slovakian volcanoes
M2: Migration of depocentres from the Viena to the Blatné basins
M3: Continuing depocentre migration in the hanging wall of the Pohorje and Rechnitz detachments
M4: Formation of depocentres near Békés Basin and Apuseni Mts (Tisza-Dacia unit).
M5: Migration of thrusting along the frontal Western Carpathians

D 15-11.6 Ma: late early Badenian to Sarmatian basin formation, volcanism and magmatism



M1: Migration of depocenters from the Békés to Makó and Szeged basins (eastern Pannonian Basin)
M2: slight migration from the Visegrád area to Zsámbék (Zs) basin
M3: Final basin migration from the Pohorje to northeast
M4: Migration of volcanism from Central Slovakian Volcanic Field toward the East Slovakian Basin (Tokaj-Slanec)
M5: Migration of basins from the Danube to the Turiec basins; M6: Migration of thrusting along the frontal Western Carpathians

Figure 2. *Evolution of sub-basins of the Pannonian Basin system, onset of basin subsidence, activity of faults, onset of rhyolitic to andesitic magmatism, and the direction and style of changes of these processes in comparison with numerical modelling results. Tectonic units on background map are after Schmid et al. (2020).*

4. Conclusions

Basin migration steps are well comparable in the numerical model and in the natural laboratory, in the followings. 1. Migration appeared from the basin margin toward the basin centre (depocenters 1 and 2). 2. A second step of migration occurred from the basin centre „backward" to the inherited weakness zone of the basin margin (depocenters 3). 3. Both subsidence and formation of acidic volcanism follow the same migration pattern. 4. Local migration within larger sub-basins equally occurred. 5. The roll-back of the subducting slab induced additional migration away from the centre (depocenters 4). 6. Deep Earth processes (e.g., mantle flow), subduction roll back governed the processes, while inherited lithospheric or crustal weakness zones also played important role.

Acknowledgements

The research was supported by the project 134873 (L. Fodor) and the National Grant Hungary project RGH-L 151351 (led by Sierd Cloetingh), both financed by the National Research, Development and Innovation Office of Hungary. T. Gerya and A. Balázs acknowledge support from the Swiss National Science Foundation Research Grant No. 200021_192296. All computations were conducted on the ETH Zürich Euler cluster.

References

Balázs A., Maţenco L., Magyar I., Horváth F. & Cloetingh S. (2016): Tectonics, 35, 1526–1559.

Balázs A., Gerya T., May D., & Tari G. (2023): Geological Society of London, Special Publications, 524, SP524–2021-94.

Fodor L., Balázs A., Csillag G., Dunkl I., Héja G., Jelen B., Kelemen P., Kövér Sz., Németh A., Nyíri D., Selmeczi I., Trajanova M., Vrabec M. & Vrabec M. (2021): Global and Planetary Change 201, 103475.

Gerya T.V. & Yuen D. (2007): Physics of the Earth and Planetary Interiors, 163, 83–105.

Lukács R. (2024): Cirkonalapú kutatások a Kárpát–Pannon térség neogén-kvarter Si-gazdag vulkáni képződményeinek korára, rétegtani szerepére és petrogenezisére. Hungarian Academy of Sciences, short doctoral thesis, 49 p.

Lukács R., Guillong M., Szepesi J., Szymanowski D., Portnyagine M., Józsa S., Bachmann O., Petrelli M., Müller S., Schiller D., Fodor L., Chelle-Michou C. & Harangi Sz. (2024): Gondwana Research, 130, 55–74.

Munch J., Ueda K., Schnydrig S., May D.A. & Gerya, T.V. (2022): Tectonophysics, 836, 229410.

Oravecz É. (2024): The effects of structural and thermo-rheological inheritance during the different stages of the Wilson cycle: new insights from 3D thermo-mechanical models and observations. PhD thesis, Eötvös Loránd University, Department of Geology.

Oravecz É., Balázs A., Gerya T., May D.A. & Fodor L. (2024): Geology, 52(6), 447-452. doi:10.1130/G51971.1

Oravecz É., Balázs A., Gerya T. & Fodor L. (2025): Journal of Geophysical Research: Solid Earth, 130 (8), e2025JB031142.

Schmid S.M., Fügenschuh B., Kounov A., Maţenco L., Nievergelt P., Oberhänsli R., Pleuger J., Schefer S., Schuster R., Tomljenović B., Ustaszewski K. & van Hinsbergen D.J.J. (2020): Gondwana Research 78, 308–374.

Šujan M., Rybár S., Kováč M., Bielik M., Majcin D., Minar J., Plašienka D., Nováková P. & Kotulova, J. (2021): Global and Planetary Change 196 103375.

Tari G. (1994): Alpine Tectonics of the Pannonian basin. PhD. Thesis, Rice University, Texas, USA. 501 pp.

Tari G., Dövényi P., Dunkl I., Horváth F., Lenkey L., Stefanescu M., Szafián P. & Tóth T. (1999): In: Durand B., Jolivet L., Horváth F. & Séranne M. (eds.): The Mediterranean Basins: Tertiary extension within the Alpine Orogen. Geological Society Special Publications 156, 215–250.

ZIRCON U-PB GEOCHRONOLOGY AND VOLCANOLOGY OF THE PYROCLASTIC ROCKS FROM THE GELÉNES-1 BOREHOLE (NE HUNGARY)

Margaréta Gazsi[1]*, Réka Lukács[1,2], Péter Gál[1,2], Marcel Guillong[3] & János Szepesi[2,4]

[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary

[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[3] ETH Zürich, Zürich, Switzerland

[4] HUN-REN Institute for Nuclear Research, Geochronology Group, Debrecen, Hungary

* E-mail: gazsi.margareta@gmail.com

The largest volcanic eruptions in the Pannonian Basin were fed by silica-rich magmas between 18.1 and 11.6 million years ago. While the Bükkalja Volcanic Field and the Tokaj Mountains are well-studied surface expressions of this volcanism, buried volcanic formations are also known from drill cores. One such area is the Nyírség region in northeastern Hungary, where the Gelénes–1 borehole, located at the eastern margin of the basin, intersected a 1394 m thick volcanic sequence between depths of 608 and 2002 meters.

A total of 19 samples were collected from the Rákóczibánya core repository for petrographic analysis and zircon separation. Macroscopic and microscopic observations indicate that the succession is dominated by pumice-bearing lapilli tuffs and tuffs, with perlite occurring at the base. The rocks are compositionally similar throughout, containing phenocrysts of quartz, feldspar, biotite, and minor amounts of sanidine.

Our results reveal two major eruptive units within the sequence — an upper and a lower unit — separated by a layer of fine tuffaceous clayey sand (tuffite), marking a pause in volcanic activity. The lower unit is slightly more quartz-rich than the upper. The basal perlite was previously interpreted by Pantó (1966) as a fully remelted pyroclastic deposit; however, the absence of clasts challenges this hypothesis. Up-section, the degree of welding decreases, but flattened pumice clasts indicate significant compaction.

Five samples taken at depths of 692 m, 749 m, 1364 m, 1842 m, and 1918 m were dated by U–Pb analysis of zircon using LA–ICP–MS. In contrast to previous, widely scattered K–Ar ages (17.2–6.8 Ma), our new results place both eruptive units in the Sarmatian (Middle Miocene), with an age of 12.0 ± 0.2 Ma. The two thick units, measuring 608 m and 772 m in thickness, were emplaced in rapid succession, with a hiatus of no more than 400,000 years. Their great thickness and structural context suggest deposition during caldera-forming eruptions into a subsiding depression.

This work was supported by the Hungarian National Research, Development and Innovation Office (No. 145905) and by the MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group.

References

Pantó G. (1966): Gelénes 1 sz. alapfúrás dokumentációja. Manuscript, Hungarian State Geological, Geophysical and Mining Archive, Budapest.

ACCUMULATION OF TECHNOLOGY METALS IN SPHALERITE: DEPENDENCE ON FORMATION CONDITIONS (TEMPERATURE, METAMORPHIC OVERPRINT)

Botond G. Gereczi[1]*, Viktor Bertrandsson Erlandsson[2], Vasilios Melfos[3] & Gabriella B. Kiss[1]
[1] Eötvös Loránd University, Department of Mineralogy, Budapest, Hungary
[2] Montanuniversität Leoben, Chair of Geology and Economic Geology, Leoben, Austria
[3] Aristotle University of Thessaloniki, School of Geology, Thessaloniki, Greece
* E-mail: gereczibg@student.elte.hu

Sphalerite is one of the most important host minerals for several technology metals, such as Cd, Ga, Ge, In, and Zn (Cook et al., 2009) and can also contain significant amounts of Co and Fe (Bertrandsson Erlandsson et al., 2022). However, details on their enrichment conditions are not available in several deposit types, including the volcanogenic massive sulphide (VMS) deposits. Therefore, sphalerite may hold greater economic significance than previously recognized.

Sphalerite samples from seven VMS deposits were analysed using SEM-EDS, EPMA, and LA-ICP-MS from the Neotethyan realm, including Fitia, Kalamaki, Rodochori, Xylagani (Greece), Gjegjan (Albania), Lasail, Aarja (Oman). Previous studies concluded that Fitia, Xylagani, Rodochori, Lasail, and Aarja are Cyprus-type VMS deposits, however, the Gjegjan and Kalamaki deposits were metamorphosed, making subcategorization difficult. Most of these mineralisations were last studied several decades ago. Therefore, in this study comprehensive modern mineralogical investigations were conducted, leading to the identification of previously unreported minerals (e.g., sperrylite, electrum, melonite, tellurobismuthite from Fitia; clausthalite, molybdenite from Kalamaki) and the reconstruction of the mineral precipitation sequence. Most sphalerite formed during the early stage of the mineralisation, although late-stage crystals also occur. Early formed sphalerite often contains chalcopyrite disease, which may interfere with the analysis of pure sphalerite. Based on SEM-EDS and EPMA data, along with Cu-Fe correlation analyses, the presence of chalcopyrite is considered certain when Cu exceeds 0.6–0.7 wt.%. After the exclusion of the suspicious datasets and the appropriate data corrections, sphalerite formation temperatures were calculated using different geothermometers, selected based on their applicability, yielding a range of <138–441 °C. However, according to Frenzel et al. (2016), temperatures exceeding 310 °C are unlikely in metamorphosed sphalerite.

Formation temperature and Fe-content allow us to determine an intermediate sulphidation state (Fontboté et al., 2017) for most ore-forming processes, except for Fitia, where it was between low and intermediate sulphidation state. This difference is also supported by the mineral precipitation series and paragenesis.

Iron, Cd, Mn, and Ge contents are generally within the typical VMS range (Frenzel et al., 2016), though anomalously low Fe and Mn values characterise Kalamaki, pointing to a possible role of regional metamorphic overprint (Lockington et al., 2014). Copper, Co, Ga, In, and Ag contents are often higher than expected in VMS deposits, likely reflecting localized variations in the formation conditions (e.g., sudden fO_2 and/or fS_2 change could cause Co content up to 1720 ppm, while low temperature could lead to Ga concentrations up to 2260 ppm). Data analysis reveals a previously unrecognized Ag-Pb-Bi(-Tl) and Cu-Ag correlation in VMS sphalerite, as the effect of possible micro- or nano-inclusions can most likely be excluded.

References

Cook N.J., Ciobanu C.L., Pring A., Skinner W., Shimizu M., Danyushevsky L., Saini-Eidukat B. & Melcher F. (2009): Geochimica et Cosmochimica Acta, 73, 4761–4791.

Frenzel M., Hirsch T. & Gutzmer J. (2016): Ore Geology Reviews, 76, 52–78.

Bertrandsson Erlandsson V., Gopon P., Waldl H., Misch D., Ellmies R. & Melcher F. (2023): Frontiers in Earth Science, 11, 1171859

Fontboté L., Kouzmanov K., Chiaradia M. & Pokrovski G.S. (2017): Elements, 13, 97–103.

Lockington A., Cook N.J. & Ciobanu C.L. (2014): Mineralogy and Petrology, 108, 873–890.

VOLCANOLOGICAL AND PETROGRAPHIC REASSESSMENT OF BOREHOLE SÁTORALJAÚJHELY-8, NORTHEAST HUNGARY

Dorka Gombos[1]*, Kitti Andrási[1]*, Réka Lukács[1,2], Péter Gál[1,2], János Szepesi[2,3] & Szabolcs Harangi[1,2]
[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[3] HUN-REN Institute for Nuclear Research, Geochronology Group, Debrecen, Hungary
* E-mail: gombosdorka0405@gmail.com; andrasikitti02@gmail.com

Among the volcanic regions of the Carpathian–Pannonian doma the Tokaj–Eperjes Mountains represent a particularly diverse area in terms of petrography and volcanology. The volcanic products range from basalts through andesites and dacites to rhyolitic lavas and pyroclastic deposits. This variability in eruption styles and compositions also bears significance from a geodynamic perspective. The N–S trending mountain range formed near the subduction suture in the northeastern Pannonian Basin during the final phase of subduction, in association with a thinned continental lithosphere.

In this study we focus on the oldest of the four major explosive eruptions from the Tokaj Mountains between 13.1 and 11.6 Ma (Lukács et al., 2024). The rhyolitic to rhyodacitic pyroclastic deposits related to the Sátoraljaújhely (SAU) eruption mark the onset of volcanic activity in the Tokaj Mountains at around 13.1 Ma. The SAU unit is exposed in the eastern to northeastern part of the range and is documented in several boreholes with cumulative thicknesses of several hundred meters. Correlation studies based on zircon U–Pb geochronology and geochemical data suggest that pyroclastic-flow-related sediments from this eruption are preserved more than 100 km from the inferred source area. These features point to a large-volume (>100 km^3), regionally extensive, caldera-forming eruption, likely centered in the eastern Tokaj Mountains.

Based on previous descriptions, three deep boreholes penetrated the SAU unit in this area indicating significant thicknesses: Sátoraljaújhely Suh-8, Széphalom Szh-2, and Rudabányácska Rbcs-1. The Sátoraljaújhely-8 borehole, located south of Sátoraljaújhely in the eastern Tokaj Mountains, was drilled in 1971 to a total depth of 1057 meters and provides a stratigraphic record of the region's volcanic and sedimentary evolution. According to the original lithological descriptions (Gyarmati, 1971), the interval between 989.6 and 653 meters contains brecciated pre-Neogene basement-originated sedimentary rocks intercalated with rhyodacitic lapilli tuffs. Between 653 and 553 m, conglomerates with a tuffaceous matrix and altered rhyodacitic lapilli tuffs with clay marl interbeds occur. The conglomerates contain gravel-sized clasts derived from the pre-Neogene basement and Neogene volcanic rocks. The upper 550 meters are dominated by pumiceous rhyodacitic pyroclastic rocks, mainly lapilli tuffs. Previous K–Ar dating results (Pécskay et al., 1986) yielded ages of 11.9 ± 0.7 Ma (at 130.2 m) and 11.8 ± 0.6 Ma (at 241.3 m), which appear inconsistent with the more recent zircon U–Pb ages obtained for the SAU unit. However, they emphasize the impacts of overall hydrothermal alteration.

The aim of our study is to refine the stratigraphic framework and volcanological interpretation of the Sátoraljaújhely Unit by assessing its age variability through zircon U–Pb geochronology, as well as its thickness, lithological heterogeneity, and eruptive history.

References

Lukács R., Guillong M., Szepesi J., Szymanowski D., Portnyagin M., Józsa S., Bachmann O., Petrelli M., Müller S., Schiller D., Fodor L., Chelle-Michou C. & Harangi Sz. (2024): Gondwana Research, 130, 53–77.

Gyarmati P. (1971): Investigation report of Sátoraljaújhely-8 structural research borehole. Hungarian Geological Instute, Budapest, pp. 1-484.

Pécskay Z., Balogh K., Széky-Fux V. & Gyarmati P. (1986): Geologica Carpathica 7, 635–655.

COPPER AND SILVER ORE POTENTIAL IN THE WESTERN MECSEK

Iván Gyenes, János Földessy*,
University of Miskolc, Faculty of Earth and Environmental Sciences and Engineering, Miskolc, Hungary
* E-mail: janos.foldessy@uni-miskolc.hu

Copper is vital in current economic strategies aiming to replace coal- and hydrocarbon-based energy sources and is a critical raw material with rapidly growing demand.

Historically, Hungarian mining focused on the Mecsek Mountains, mainly for uranium and black coal. Less studied is the sediment-hosted, stratabound copper-silver mineralization in the Permian–Triassic transitional layers of the Western Mecsek. This study summarizes available data as a predictive evaluation.

The NW–SE trending West-Mecsek anticline contains the Lower Permian Boda Aleurolite Formation in its core overlain by the Upper Permian Kővágószőlős Sandstone Formation in the Boda and Bakonya regions. The eastward-plunging anticline exposes progressively younger formations eastward, including the Permian–Triassic Jakabhegy Sandstone and Patacs Aleurolite, followed by younger Triassic strata further north. The anticline's axis follows the Bakonya–Pécs line, ending near Pécs along a meridional fault zone.

Copper-silver enrichments have been known since the 1960s, described in surface outcrops and mining/drill cores (Várszegi, 1965). They occur at two levels: on the Lower to Upper Permian boundary and in the Permian–Triassic transitional sequence. The latter was intersected by numerous uranium exploration boreholes in the 1960s but remained unassessed (Virágh & Várszegi, 1965).

The Cu-Ag mineralization closely resembles Polish copper shale deposits in stratigraphy and ore minerals. The copper shale horizon at the Permian–Triassic boundary includes several persistent stratiform enrichment intervals, typically less than 2 meters thick with considerable lateral continuity. Typical minerals include chalcocite, covellite, chalcopyrite, pyrite, marcasite, and cobaltite. Silver is notably high, with possible local Au and Bi enrichments (Katona, 2014).

Estimating the near-surface occurrence in Western Mecsek, continuity was assumed between the Pécs-Égervölgy and Petőcz ventillation shaft areas, with an average dip of 25°. The mineralized layer was traced from surface to 131 m depth, with an average thickness of 1.5 m and bulk density of 2 t/m³. This outlines a zone about 400 m down dip and 7,000 m along strike, with concentrations near 0.6% Cu and 60 g/t Ag.

This segment of the enriched body's estimated mass is 8.4 million tonnes. Given several other copper-bearing intersections in uranium drill cores, the mineralization likely extends beyond this volume. Detailed re-evaluation of stratigraphy and samples from earlier uranium exploration is needed for better estimates.

The economic potential is reflected by recoverable metals (Cu, Ag) valued at around 110 USD/tonne ore, totaling an estimated 920 million USD (322 billion HUF).
In summary, earlier data indicate a potential for significant industrial-grade mineralization similar to other European deposits. Further low-risk exploration is possible and may uncover critical mineral resources, potentially through reopening upper sections of former underground uranium mines.

References

Katona G. (2014): A Rudna (Lengyelország) perm és Mecsek perm-alsó triász Patacsi Formáció rétegkövető ércesedéseinek összehasonlító földtani és geokémiai vizsgálata. MSc theses, University of Miskolc.

Várszegi K. (1965): Bulletin of the Hungarian Geological Society, 95(4), 437–438.

Virágh K. & Várszegi K. (1967): A petőczi légakna környékén végzett rézkutatásokról. Data Repository of the Mecsek Ore Mining Company, manuscript J1923.

CONTROL OF EFFUSIVE AND EXPLOSIVE ERUPTIONS OF CIOMADUL VOLCANO: CONSTRAINTS BY APATITE COMPOSITION

Krisztina Hajdu[1,2]*, Razvan-Gabriel Popa[3], Szabolcs Harangi[1,2], Julien Marius Allaz[3], Emese Pánczél[1,2], Barbara Cserép[1,2], Olivier Bachmann[3], Máté Karlik[4], Elemér Pál-Molnár[5], Ioan Seghedi[6] & Réka Lukács[1,2]

[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary

[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[3] ETH Zürich, Institute of Geochemistry and Petrology, Department of Earth Sciences, Zürich, Switzerland

[4] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[5] University of Szeged, Department of Mineralogy, Geochemistry and Petrology, Szeged, Hungary

[6] Romanian Academy, Institute of Geodynamics Sabba S. Ştefanescu, Bucharest, Romania

* E-mail: tsunamisucks@gmail.com

The Ciomadul Volcanic Complex, Eastern Carpathians, Romania is the youngest volcano in the Carpathian-Pannonian region, where volcanic activity occurred between 160 ka and 30 ka. It is a typical long-dormant volcano, where active stages were divided by several 10s kyr quiescence. Geophysical studies indicate that it is still underlain by a potentially active magma storage. Two main stages of volcanism are distinguished that are separated by ca. 40 kyr dormancy: the first eruptive episode from 160 ka to 95 ka was characterized by lava dome extrusions, followed by a mixed explosive and extrusive eruptive stage from 55 to 30 ka. Bulk rock composition, however, remained high-K dacitic and homogeneous. The dacitic volcanic products are composed of plagioclase, amphibole, biotite as well as accessory apatite, titanite, Fe-Ti oxides, zircon and allanite. Olivine, clino- and orthopyroxene as well as quartz and K-feldspar occur occasionally. In this study, we focus on the apatite, particularly the variation in volatile content with an aim to reveal how it reflects the eruption type control. We analyzed the chemical composition of apatite microphenocrysts and inclusions enclosed by amphibole and biotite phenocrysts from lava dome rocks and pumices of both eruptive stages. We focus on the halogen contents (Cl, F), while the OH-content was calculated based on stoichiometry. The MgO content of the apatite was used to follow the behavior of the halogens during the magma differentiation, where higher amount of MgO represents the less evolved magma. We also analyzed the composition of the host amphibole crystals next to apatite inclusions to constrain the conditions of the apatite crystallization during the magma evolution.

The apatite data are plotted on a xCl/xOH vs xF/xOH diagram, where a breakpoint indicates the change of water-saturation state in the magma reservoir, due to the different behavior of Cl and F in water-saturated versus unsaturated states. Fluor remains in the melt during water-saturation state, as it does in water-undersaturated conditions. In contrast, Cl shows similar incompatible behavior in water-undersaturated state, yet in water-(over)saturated conditions it partitions to the gas phase, so its content in the melt (and in the crystal lattice of apatite) is buffered or decreased.

We conclude that effusive eruptions occurred when the magma reached water-(over)saturated state at constant Cl-content. In this case, the eruption triggering recharge event was not able to return the magma to water-undersaturated condition. On the contrary, the explosive events were characterized by magmas becoming water-undersaturated. In the case of the three oldest explosive eruptions the water-saturated felsic magma in the magma storage was returned to water-undersaturated state before the explosive eruptions by the mafic recharge material. Host amphibole compositions represent mostly low-temperature crystal mush, whereas occasionally high-temperature recharge and hybrid magma phases occur. Notably, all apatite inclusions having water-saturated compositions are found in the low-Mg amphiboles derived from the felsic crystal mush magma, meanwhile apatite with water-undersaturated composition can be found in all the amphibole groups, and show no systematic distribution between recharge or hybrid magma or pre-eruptive state.

In accordance with the results of previous studies our apatite focused study also confirms the role of mafic magma recharge in the petrogenesis of the Ciomadul volcano.

MULTIPLE VEIN FORMATION EVENTS IN THE WESTERN MECSEK AREA

Ervin Hrabovszki[1,2]*, Amadé Halász[3] & Félix Schubert[1]
[1] University of Szeged, Department of Geology, Szeged, Hungary
[2] University of Debrecen, Department of Mineralogy and Geology, Debrecen, Hungary
[3] Public Limited Company for Radioactive Waste Management, Budaörs, Hungary
* E-mail: ervin.hrabovszki@geo.u-szeged.hu

The long-term management of high-level radioactive waste in Hungary requires the establishment of a deep geological repository in the coming decades. The Boda Claystone Formation in the Western Mecsek region has been identified as a potential host rock due to its favourable geometry and petrophysical characteristics. However, the influence of fractures and related fluid migration remains a key issue that requires further investigation.

This study focuses on tectonic veins within the Boda Claystone as well as the underlying and overlying formations, including the Gyűrűfű Lapilli Tuff, the Cserdi, and the Kővágószőlős Sandstone Formations. Through the analysis of vein microstructures, mineralogy, geochemistry, and by comparing these features across various lithological units, the study aims to investigate whether the different structural and fluid transport processes have affected older and younger formations. Furthermore, the results offer insights into the relative timing of the tectonic deformation and fluid migration events during the geological evolution of the Western Mecsek area.

The studied samples were collected from the BAT–4, BAF–3, BAF–3A, and BAF–4 boreholes. The petrographic analysis of the mineral veins was carried out using a combination of polarizing and cathodoluminescent microscopy, as well as Raman spectroscopy at the Department of Geology, University of Szeged. Samples from BAF–3 and BAF–3A were analysed for their stable carbon and oxygen isotope compositions and fluid inclusion thermometric data. Ongoing investigations at the HUN-REN Institute for Nuclear Research (Debrecen) include clumped isotope and strontium isotope analyses on samples from the BAT–4 and BAF–4 boreholes.

Previous studies on samples from the BAF–2 borehole identified four vein generations in the Boda Claystone, each related to distinct tectonic regimes and fluid flow mechanisms. Braided veins with cone-in-cone structures formed during diagenesis by atectonic processes. These were followed by straight veins, cemented by minerals precipitating from advectively migrating basinal brines during extensional tectonics. A subsequent compressional phase produced en echelon vein arrays where mineral precipitation was controlled by local diffusive processes. Finally, hydraulic breccia veins reflect the influx of meteoric fluids. The veins are predominantly filled with calcite; older generations frequently contain albite, while anhydrite, barite, and celestine (±quartz, sulphides) are also locally present. Fluid inclusion homogenisation temperatures (T_h) in the calcite phases range dominantly between 100 and 150 °C, except in the breccia veins (40–50 °C).

In boreholes BAF–3 and BAF–3A, six distinct vein generations have been identified within the Boda Claystone, four of which correlate with those documented in the BAF–2. Additional vein generations are characterised by crack-seal microstructures featuring stretched calcite crystals and by thick (over 5 cm) anhydrite-dolomite infills. Isotopic analyses ($\delta^{18}O$) and fluid inclusion data (T_h between 70 and 120 °C) suggest that the thick veins were precipitated from basinal brine, whereas the crack-seal veins likely indicate mixing between basinal and meteoric fluids.

Veins observed in the Cserdi Formation (BAF–4), show straight geometry and their maximum thickness is 0.5 cm. These veins are filled with quartz and dolomite crystals, showing a texture characteristic for syntaxial vein development and advective fluid migration through open fractures. Comparable veins composed of multiple generations of quartz with minor dolomite occur in the underlying Gyűrűfű Lapilli Tuff. In contrast, in the Kővágószőlős Sandstone (BAT–4), 3–4 mm thick veins are filled with fine-grained and blocky calcite, dolomite, barite, and quartz, suggesting syntaxial growth and advective fluid migration.

In order to reconstruct the tectonic and fluid migration history of the area, veins with similar features, such as syntaxial dolomite-quartz infills, observed in several lithological units of the Western Mecsek region, will be compared based on fluid inclusion data and geochemical characteristics. These ongoing investigations are expected to provide further information on whether these occurrences are genetically related or represent independent events.

This research was supported by the Public Limited Company for Radioactive Waste Management, Hungary. The project is supported by the Hungarian Scientific Research Fund "OTKA" (PD_23 147180 project) and the University Research Scholarship Program (EKÖP-24-4-SZTE-625 project), funded by the Ministry of Culture and Innovation through the National Research, Development and Innovation Fund.

THE FIRST ORE-PROSPECTING SONIC DRILLING IN THE MECSEKALJA SHEAR ZONE, SOUTH HUNGARY: PRELIMINARY RESULTS

Viktor Jáger*, Gyula Maros & Márton Palotai
Supervisory Authority of Regulatory Affairs, Geological Survey of Hungary, Budapest, Hungary
* E-mail: viktor.jager@sztfh.hu

The model of orogenic gold mineralization — formed along structural zones and induced by CO_2-rich, low-salinity fluids generated during metamorphic processes — is relatively recent. It first emerged during the 1980s, but became widely accepted from the 1990s onwards, primarily due to the work of Groves et al. (1987, 1998) and Goldfarb et al. (1997).

Building on our earlier results (Jáger et al., 2023, 2024), we successfully drilled a series of prospecting boreholes across the Mecsekalja Shear Zone in the spring of 2025. These boreholes intersected the upper greenschist-facies metamorphic rocks within the tectonic zone. These efforts are essential, as the investigation of orogenic mineralization in the Mecsekalja Zone is limited by highly sporadic and small-scale surface exposure. Hence, future progress depends on deep drilling and geophysical methods. Drilling was conducted using an Eijkelkamp-Fraste CRS-F-XL 140 Compact Rotosonic rig, with dual-wall casing and water-cooled drill bit. The core diameter was 65 mm. The three inclined boreholes intersected the foliation and were drilled between the settlements of Ófalu and Mőcsény, reaching total lengths of 34 m, 42 m, and 52 m, respectively. Due to unstable borehole conditions, casing was only applied to depths of up to 10 m. Following completion, downhole geophysical logging was performed in two boreholes. The laboratory analyses of the core samples are ongoing.

In addition to intersecting the area's characteristic gneiss, amphibolite, sericite phyllite, and chlorite schist, we also identified a previously undocumented rock type in Hungary: listvenite. This metasomatic rock is composed mainly of quartz, dolomite, minor phyllosilicates, and ferrichromite. The two boreholes drilled near Mőcsény revealed crosscutting generations of dolomitic-quartz veins. In the listvenite, ferrichromite grains are rimmed by pyrite, accompanied by Ni-Co-As sulfide precipitates and barite. Interestingly, in several samples, marcasite was found to fill fractures and even occurred along the foliation planes within phyllosilicates. The Ófalu borehole also provided new subsurface information not previously identified in outcrops. Intense arsenopyritization occurred at multiple levels, both within foliation planes and crosscutting fractures, accompanied by pyrite, which typically represents a later mineralization phase. Based on SEM-EDS analyses, electrum and native gold occur as nano- to micro-inclusions within arsenopyrite associated with Bi-tellurides. Some thin mineralized bands, parallel to the foliation of the chlorite schist, contain abundant Ni-sulfide, chalcopyrite, and lesser galena within carbonate-quartz vein systems. The co-occurrence of ferrichromite in this rock type points to an ultramafic–mafic precursor. Notably, this ~80 cm interval is clearly identifiable on the borehole geophysical log as a zone of elevated magnetic susceptibility.

The dominant alteration types include carbonation (dolomite, siderite with minor calcite), chloritization (also along veins), silicification, biotitization, sericitization, and sulfide mineralization (pyrite, arsenopyrite, marcasite, and Ni-Co sulfides). LA-ICP-MS elemental mapping reveals that gold displays oscillatory zoning parallel to the growth surfaces of pyrite, which indicates pulsed variations in fluid composition and syngenetic incorporation of gold.

References

Goldfarb R.J., Miller L.D., Leach D.L. & Snee L.W. (1997): In: Goldfarb R.J. & Miller L.D. (eds.): Mineral Deposits of Alaska. Economic Geology Monograph, 9, 151–190.

Groves D.I., Phillips G.N., Ho S.E., Houstoun S.M. & Standing C.A. (1987): Economic Geology, 82, 2045–2058.

Groves D.I., Goldfarb R.J., Gebre-Mariam H., Hagemann S.G. & Robert F. (1998): Ore Geology Reviews 13, 7–27.

Jáger V., Molnár F. & Király E. (2023): Bulletin of the Hungarian Geological Society, 152, 307–329.

Jáger V., Héja G.H., Dabi G. & Lukoczki G. (2024): Palaeogeography, Palaeoclimatology, Palaeo-ecology, 650, 112372

TRACING A 13.06 MA PHREATOMAGMATIC IGNIMBRITE FROM THE MÁTRA MTS. TO THE TOKAJ MTS.: A SNAPSHOT OF THE PALEOENVIRONMENT OF THE CENTRAL PARATETHYS

Dávid Karátson[1*], Pierre Lahitte[2], Maxim Portnyagin[3], Márton Palotai[4], Sándor Józsa[5], Emő Márton[6], Emőke Tóth[7], Boglárka Erdei[8], Nomade Sébastien[9], Károly Németh[10,11,12], Levente Iván[1], Márton Krasznai[1], Fanni Vörös[1], Tamás Biró[1], Jean-Louis Paquette†[13], Lilla Hably[8], János Hír[14], Péter Prakfalvi[15], János Kiss[16], Zoltán Pécskay[17], Daniel A. Frick[18] & Mátyás Hencz[1,10]

1 Eötvös Loránd University, Department of Physical Geography, Budapest, Hungary
2 Université Paris-Saclay, Laboratoire GEOPS, CNRS, Orsay, France
3 GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany
4 Supervisory Authority for Regulatory Affairs, Geology and Laboratory Department, Budapest, Hungary
5 Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
6 Supervisory Authority for Regulatory Affairs, Paleomagnetic Laboratory, Budapest, Hungary
7 Eötvös Loránd University, Department of Paleontology, Budapest, Hungary
8 Hungarian Natural History Museum, Budapest, Hungary
9 Université de Versailles St-Quentin et Paris-Saclay, Laboratoire des Sciences du Climat et de l'Environnement, CEA, Gif-sur-Yvette, France
10 HUN-REN Institute of Earth Physics and Space Sciences, MTA-EPSS FluidsByDepth Lendület Research Group, Sopron, Hungary
11 Saudi Geological Survey, National Program of Earthquakes and Volcanoes, Jeddah, Saudi Arabia
12 Massey University, Volcanic Risk Solutions, Palmerston North, New Zealand
13 Université Clermont Auvergne, Laboratoire Magmas et Volcans, Clermont-Ferrand, France
14 Natural History Museum, Pásztó, Hungary
15 Supervisory Authority for Regulatory Affairs, Department of Geological, Geophysical and Mining Data Store, Budapest, Hungary
16 Supervisory Authority for Regulatory Affairs, Department of Mineral Raw Material Exploration and Geophysics, Budapest, Hungary
17 HUN-REN Institute for Nuclear Research, Debrecen, Hungary
18 Institute of Geosciences, Christian-Albrechts-University Kiel, Kiel, Germany
* E-mail: karatson.david@ttk.elte.hu

Following a conference presentation (Biró et al., 2024) and an international publication (Karátson et al., 2025), here we present for the first time in Hungary the volcanological and paleoenvironmental features of a 13.06 Ma large explosive eruption which we refer to as the Dobi Ignimbrite. Representing one of the youngest members of the voluminous Miocene silicic volcanism sourced mainly from the North Pannonian Basin (e.g., Hencz et al., 2024; Lukács et al., 2024), it covered an area of >3150 km^2 in North Hungary. Its precise sanidine/plagioclase $^{40}Ar/^{39}Ar$ dating yielded an age of 13.064 ± 0.065 Ma (~Badenian/Sarmatian boundary in Central Paratethys chronology). The ignimbrite has distinctive glass geochemistry with wide compositional variations, which conforms with large-scale silicic explosive eruptions. Accordingly, the calculated minimum volume (~200 km^3) is consistent with a VEI 7 eruption, with possible ultradistal transport distance of >300 km. Most of the pyroclastic succession was emplaced on land, as it contains leaves and tree trunks in the basal layer that we correlate with the Badenian/Sarmatian 'volcanic floras' of northern Hungary. At the same time, the ignimbrite has a phreatomagmatic character and contains free-floating foraminifera, suggesting that the source vent was in coastal waters. These findings indicate either a late Badenian marine incursion prior to the eruption, or the shift of the eruption center toward the sea.

References

Biró T. et al. (2024): EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-20357
Hencz M. et al. (2024): Journal of Volcanology and Geothermal Research, 445, 107960
Karátson D. et al. (2025): Scientific Reports, 15, 23528
Lukács R. et al. (2024): Gondwana Research, 130, 53–77.

RECONSTRUCTING THE PAST: PRELIMINARY PALEOENVIRONMENTAL DATA FROM LAKES IN THE CARPATHIANS

Máté Karlik[1]*, Fruzsina Gresina[1], Anna Vancsik[1], Gábor Bozsó[2], Marcel Mindrescu[3] & Ionela Grădinaru[4]*

[1] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[2] University of Szeged, Department of Geology, Szeged, Hungary

[3] Ștefan cel Mare University, Department of Geography, Suceava, Romania

[4.] Fluturica, Romania

* E-mail: karlikmate@gmail.com; ionela.gradinaru@gmail.com

A wide range of geological formations can be used for environmental reconstruction—particularly those that exhibit stratified sequences through time.

The Carpathian Mountains offer numerous opportunities for a wide range of scientific investigations, particularly in the field of geomorphology. Owing to their extensive vertical and horizontal dimensions, the region has been the focus of many past studies, which have aimed not only to understand present-day processes—such as forest management—but also to trace environmental changes and detect paleoenvironmental markers. The Carpathians host a variety of valuable natural archives, including speleothems, ice caves, paleosols, and unique lakes.

The selection of a suitable lake for paleoenvironmental reconstruction requires extensive fieldwork. Particular attention must be paid to identifying sites where undisturbed sedimentation has occurred—free from mixing or bioturbation. Ideal candidates are typically small in surface area but relatively deep, conditions that promote well-preserved, continuous, and stratified sediment records.

Among these, lake sediments represent a key archive in the toolkit of paleoclimate and paleoenvironmental reconstruction.

Lake sediments preserve both organic and inorganic signatures of the surrounding environment at the time of deposition. These records provide insight into vegetation dynamics and capture major events that alter the dominant kinetic conditions of the catchment area, such as storm events or seismic activity.

Due to their inherent complexity, lake sediments can be studied from both an inorganic and organic geochemical perspective. Special attention is often given to inorganic geochemical proxies, organic biomarkers, preserved macrofossils, and pollen content, all of which contribute to a multifaceted reconstruction of past environmental conditions.

In the present study, we focus on two lakes of particular interest: Lake Bolătău and Lake Botoșani. These lakes exhibit a combination of characteristics that make them promising candidates for paleoenvironmental reconstruction.

Sediment cores were sectioned while frozen and subsequently sliced into 1-centimeter intervals for further analysis.

Research on Lake Bolătău has been ongoing for several years, resulting in multiple publications and doctoral dissertations based on the collected data. (Karlik et. al. 2021, 2024) In contrast, the investigation of Lake Botoșani has only recently begun, with a freshly recovered sediment core. Despite the difference in research history, the sediment profiles from the two lakes appear to be of similar age.

Comparison of the data—including grain size distribution, elemental composition, etc.—revealed clear signals corresponding to major climatic events such as the Maunder Minimum and the Roman Climate Optimum. Naturally, both sites also reflect location-specific characteristics, particularly with respect to local disturbance events such as storms.

References

Karlik M., Vancsik A., Szalai Z., Fekete J., Bozsó G., Gradinaru I. & Mindrescu M. (2024): Geoconcept Journal, 5(1), 42–44.

Karlik M., Vancsik A., Szalai Z., Mîndrescu M., Grădinaru I., Vágási S., Bozsó G. & Fekete J. (2021): Hungarian Geographical Bulletin 70(4), 339–351.

THE CO_2-RICH GAS EMISSIONS OF THE CARPATHIANS: GEOCHEMISTRY AND ORIGIN OF FLUIDS

Boglarka Mercedesz Kis[1,2]*, Réka Szalay[1], Szabolcs Harangi[2], Tivadar M. Tóth[3], Antonio Caracausi[4], Paolo Randazzo[4], László Palcsu[5]
[1] Babeș-Bolyai University, Department of Geology, Cluj-Napoca, Romania
[2] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[3] University of Szeged, Department of Geology, Szeged, Hungary
[4] Istituto Nazionale di Goefisica e Vulcanologia, Palermo, Italy
[5] HUN-REN Institute for Nuclear Research, Debrecen, Hungary
* E-mail: boglarka.kis@ubbcluj.ro

The mountain range of the Western and Eastern Carpathians hosts several gas emissions, that are present at the vicinity of the Neogene to Quaternary volcanic range or in the thrusted and folded flysch belt, e.g. the Ceahlau-Severin nappe systems in Romania or in the Magura nappe systems in Poland. These are predominantly CO_2-dominated emissions, but other gas-species, like CH_4, N_2 or H_2S are also present (Vaselli et al., 2000; Kis et al., 2019). The gas emissions appear as free gases, mofettes or they are transported to the surface through groundwater and form CO_2-rich mineral water springs or bubbling pools (Kotarba et al., 2020 Kis et al., 2020). While extensive research has been conducted on the origin and generation of hydrocarbons primarily due to their economic significance and exploration interests (Kotarba & Nagao, 2008; Pawlewicz, 2007), the origin, sources and geological/geochemical processes responsible for CO_2 generation – the second most abundant gas phase of the Carpathians – remain still unclear.

The integration of our newly acquired gas-geochemical data with the results of previous investigations has enabled a more comprehensive understanding of natural gas emissions across the Western and Eastern Carpathians. This dataset has made it possible to produce the first regional-scale map of the spatial distribution of free CO_2 and CH_4 degassing sites. The systematic mapping and synthesis of these occurrences reveal that the two principal gas species, CO_2 and CH_4, exhibit markedly different spatial distributions. These differences are interpreted to reflect underlying variations in lithological composition. The aim of our study is to constrain the origin of CO_2-rich gas emissions by analyzing the carbon and noble gas (especially helium and neon) isotopic compositions. These geochemical tracers provide crucial insights into the provenance and migration pathways of deep-seated volatiles. Our isotopic data reveal that the CO_2-rich gases have a mixed origin, with contributions from several distinct sources. These include (i) mantle- and/or magmatic-derived fluids, characterized by elevated helium isotope ratios (R/Ra values reaching up to 3.2); (ii) metamorphic processes, likely involving decarbonation reactions in carbonate-bearing lithologies; and (iii) minor contributions from the thermal degradation of organic material embedded within the flysch sequences, which is typically associated with crustal helium signatures and isotopically depleted carbon in CO_2.

One of the most striking anomalies identified in the dataset is located in the Ciomadul volcanic area of the Eastern Carpathians (Romania), where the highest R/Ra values recorded across the entire Carpathian region are observed. This supports the correlation between the presence of a mantle/magmatic-derived component in the gases and recent volcanic activity, consistent with previous volcanological and geophysical findings from the region. Furthermore, a systematic lateral decrease in R/Ra values is observed when moving away from volcanic range towards the adjacent flysch belt. This highlights the role of deep faults and fracture systems in acting as preferential conduits for the upward migration of mantle-derived volatiles into overlying non-volcanic regions. The $\delta^{13}C$-CO_2 and $CO_2/^3He$ relationships indicate a combination of mantle and crustal sources, with secondary modifications at shallow level altering the isotopic signatures.

This work was supported by a grant PN-III-P1-1.1-TE-2019-1908, contract number TE 63/2020.

References

Kis B., Caracausi A., Palcsu L., Baciu C., Ionescu A., Futó I., Sciarra A. & Harangi, Sz. (2019): Geochemistry, Geophysics, Geosystems, 20, 3019–3043.

Kis B.M., Baciu C., Zsigmond A.R., Kékedy-Nagy L., Kármán K., Palcsu L., Máthé I. & Harangi Sz. (2020): Journal of Hydrology, 591, 125311

Kotarba M.J. & Nagao K. (2008): Chemical Geology, 255, 426–438.

Pawlewicz M. (2007): U.S. Geological Survey Bulletin, 2204-F.

Vaselli O., Minissale A., Tassi F., Magro G., Seghedi I., Ioane D. & Szakács A. (2002): Chemical Geology, 182, 637–654.

2D S-WAVE REFLECTION SEISMIC SURVEY IN THE WEST-MECSEK MTS.: NEW INSIGHTS INTO SHALLOW GEOLOGY AND NEOTECTONICS

Balázs Koroknai[1]*, Zoltán Kádi[1], Tamás Tóth[1], Gergely Dövényi[1], Géza Wórum[1], Gyula Konrád[2], Amadé Halász[3], Péter Molnár[3]

[1] Geomega Ltd., Budapest, Hungary

[2] Kővágótöttős, Hungary

[3] Public Limited Company for Radioactive Waste Management, Budaörs, Hungary

* E-mail: koroknai@geomega.hu

New 2D S-wave reflection seismic survey was carried out in the West Mecsek Mts. and its southern and western foreland during late 2024 and early 2025. This new research — related to the long-term geological research program of the Permian Boda Claystone Formation — included the measurement of 11 2D S-wave reflection seismic profiles (detected with fixed Stryde sensors) over a total length of 56.3 km. In addition to the 11 fixed-sensor 2D S-wave seismic profiles, 20 km of trailed LandStreamer profiles were also measured in order to obtain a better seismic imaging of the near-surface geological layers.

The basic aims of this new seismic survey were

– to image and understand the thickness and depositional relationships of the younger (Miocene, Pannonian and Quaternary), less consolidated sediments with low(er) S-wave propagation velocities overlying the high-velocity basement formations,

– to study the neotectonic activity (i.e. the last 6–8 Ma) of tectonic structures previously known in the study area, and

– to provide information for the design of future water monitoring well groups in the West Mecsek foreland.

This presentation — following a short methodological introduction — will give a brief overview on the most important geological and tectonic results of the new 2D S-wave reflection seismic survey. The new seismic survey resulted in a high quality seismic data set, well beyond preliminary expectations. The new data provided important and otherwise not available, high-resolution knowledges on shallow-seated geological formations (Quaternary, Pannonian, partly also on Miocene), as well as on (neo)tectonics. Therefore, the new seismic data also represent a supplement of basic importance to the previous P-wave 3D seismic data cube in the West-Mecsek Mts. (measured by Geofizyka Torun in 2022), focused mainly to the seismic imaging of basement formations.

The new seismic data enable the refinement of the geological-structural model of the West Mecsek Mts. and its foreland. The preliminary geological interpretation included the seismic interpretation of three key geological horizons — top-basement, top-Miocene and top-Pannonian — taking into account the seismic facies, the tomographic velocity field and available well data. In addition to the above horizons, the interpretation of the main faults/fault zones was also performed. Overall, the completed preliminary interpretation confirms and clarifies the position of the main structural elements depicted by Konrád (2023) and also highlights several additional elements. The structural interpretation confirmed marked neotectonic activity along several structural elements, especially along the Mecsekalja fault zone and in the area of the so-called „Southern imbricate belt”. In the West Mecsek Mts, neotectonic activity presumably occurred along the Hetvehely-Magyarszék fault zone.

References

Konrád Gy. (2023): A mecseki permotriász képződmények litosztratigráfiája és szerkezeti helyzete. Research report, Public Limited Company for Radioactive Waste Management, RHK-N-012/23

REINTERPRETING THE ROLE OF EVAPORITE-DRIVEN DEFORMATION IN THE INNER WESTERN CARPATHIANS DURING THE OPENING AND CLOSURE OF THE NEOTETHYS OCEAN

Szilvia Kövér[1,2]*, Ádám Csicsek L.[3], Oscar Fernandez[4], László Fodor[1,2], Bernhard Grasemann[4], Christoph Leitner[5], Gianreto Manatschal[6] & Tomáš Potočný[7]

[1] HUN-REN Institute or Earth Physics and Space Science, Sopron, Hungary
[2] Eötvös Loránd University, Department of Geology, Budapest, Hungary
[3] University of Granada, Department of Geodynamics, Granada, Spain
[4] University of Vienna, Department of Geology, Vienna, Austria
[5] University of Salzburg, Department of Environment and Biodiversity, Salzburg, Austria
[6] University of Strasbourg, Institute of Earth and Environment, Strasbourg, France
[7] Comenius University, Department of Geology and Paleontology, Bratislava, Slovakia
* E-mail: kover.szilvia@epss.hun-ren.hu

The two most dynamic and intriguing evolutionary stages of a continental margin are the stretching of the lithosphere leading to break-up, and its subsequent shortening and incorporation into an orogenic wedge. These phases become even more complex in evaporite-rich margins. In our recent research in the Western Carpathians, we investigated the role of salt tectonics during the multi-stage evolution of a Neotethyan margin, from Permian–Middle Triassic rifting to mid-Cretaceous nappe stacking. The reconstructed evolutionary sequence includes:

1. Early Salt-Related Deformation (late Early Triassic): This stage was marked by significant thickness variations within the sedimentary succession, as well as slump folds and syn-sedimentary fault structures, indicating active salt tectonics (passive diapir formation).

2. Crustal Stretching and reactive Diapirism (Late Anisian–Early Ladinian): General stretching of the upper crust led to the drowning of carbonate ramps in the outer shelf and the emplacement of early rift-type basalts in distal regions, likely within the necking zone. Normal faulting initiated reactive diapirism in the evaporite-rich proximal margin, resulting in the formation of mini-basins infilled with thick shallow-marine carbonates. This process continued until the Norian, accompanied by the collapse of diapir crests and the development of intraplatform basins.

3. Break-up and Mantle Exhumation (Late Carnian–Early Norian): Break-up was accompanied by exhumation and intense serpentinization of subcontinental mantle rocks, which were subsequently exposed at the seafloor.

4. Gravitational Gliding onto the Exhumed Mantle: Portions of the mini-basin system glided over the exhumed mantle along a basal evaporite detachment. This process led to:

a) drowning of the carbonate platforms within the mini-basins;

b) formation of an evaporitic mélange containing blocks from the outer margin, necking zone, and mantle (e.g., basalt with Ladinian radiolarite cover, gabbro, serpentinite, sedimentary breccias, and pelagic sediments);

c) localized high-temperature, low-pressure metamorphism and ductile mylonitization at the base of mini-basins in direct contact with the hot mantle (basal weld zones).

5. Post-Gliding Sedimentation (Middle Jurassic): Pelagic siliciclastic sedimentation occurred in both the foreland and hinterland of the allochthonous mini-basin system. Continued salt movement led to diverse mid-Jurassic sedimentation patterns within the mini-basins and former diapir-top depressions.

6. Subduction and Nappe Stacking (Middle–Late Jurassic): The exhumed mantle, necking zone, and distal continental margin underwent subduction with high-pressure metamorphism. The basal evaporites and welds of the allochthonous mini-basins acted as detachment surfaces, allowing the overlying sedimentary basins and mélange blocks to escape HP overprinting. This culminated in an early nappe-stacking phase (Late Jurassic), with the mini-basins emplaced onto various basement/cover units.

7. Exhumation and Early Shortening: The exhumation of HP rocks occurred concurrently with early shortening and the onset of thick-skinned nappe stacking of the lower plate margin.

Conclusion: Salt tectonics played a critical role in both the early rift-related and later compressional phases of evolution of the Neotethyan margin in the Western Carpathians, fundamentally influencing structural development and sedimentation throughout its complex history.

A MINERALOGICAL, PETROGRAPHICAL, GEOCHEMICAL, AND NOBLE GAS ANALYSIS OF TWO SAHARAN METEORITES

Balázs Küzmös[1,2]*, Gergely Szabó[3], Ulrich Ott[1], Kata Molnár[1], János Szepesi[1], Christoph Hauzenberger[4] & Zsolt Benkó[1,2]

[1] HUN-REN Institute for Nuclear Research, Geochronology Lab, Debrecen, Hungary
[2] University of Debrecen, Department of Mineralogy and Geology, Debrecen, Hungary
[3] University of Debrecen, Department of Physical Geography and Geoinformatics, Debrecen, Hungary
[4] Karl-Franzens University, Graz, Austria
* E-mail: balazskuzmos@gmail.com

Our research aimed to classify two North-West Africa meteorites, based on petrographical, mineralogical and geochemical properties, with the hopes of gaining a better understanding of their formation and parent bodies.

Polarizing microscope analysis determined that NWA1 and NWA2 consist of chondrules and matrix material, thus landing them in the group of chondrites. The chondrules often appear with „blurry" outlines, showing a transitionary state between their own material and that of the matrix. Both meteorites lack smaller chondrules, which can be explained by the gradual reheating of their materials altering the primary chondritic texture. NWA2 suffered a slightly higher level of reheating than NWA1 (Van Schmus & Wood, 1967).

The chondrules are made up of olivine and orthopyroxene, while the recrystallized matrix material consists of olivine, monoclinic- and orthopyroxene, Fe-Ni alloys, and plagioclase crystals. Fe-oxides-hidroxides can also be observed in the many shock-veins running through the rocks. Furthermore, planar fractures in olivine crystals, and the undulatory extinction of olivine and plagioclase minerals suggest a history of shock-events, causing weak shock-metamorphism (Stöffler et al., 1991).

Microprobe analysis showed olivine to be forsterite (NWA1: $Fa_{18.4}$ and NWA2: $Fa_{24.7}$), orthopyroxene to be enstatite (NWA1: $Fs_{16.8}$ and NWA2: $Fs_{21.6}$), and plagioclase to be oligoclase (NWA1: $An_{10.7}Ab_{83.3}Or_{6}$ and NWA2: $An_{10.7}Ab_{82.3}Or_{6}$) in composition. Both meteorites show a very low content of rare-earth elements (ΣREE_{NWA1}: 4.82 ppm and ΣREE_{NWA2}: 5.55 ppm), with a slight enrichment in light rare-earth elements. The low REE contents suggest parent bodies that remained largely unaltered since their formation roughly 4.54 billion years ago.

Both meteorites show signs of terrestrial weathering, such as the disappearance of their fusion crusts, brownish stains caused by limonite, and the oxidation of Fe-Ni metals. NWA2 suffered a higher level of weathering than NWA1 (Wlotzka, 1993).

NWA1 was recovered from an unknown location with an original mass of 50.3 g. After examination, it was classified as a moderately recrystallized and equilibrated – petrologic type 5 – ordinary „H" (high-iron) chondrite. It suffered weak – S3 type – shock metamorphism with shock pressures of 15-20 GPa, and weak – W2 type – weathering, with its terrestrial age ranging between 5 – 15 ka. Following these results, NWA1 received the name H5S3W2, referencing its characteristics.

NWA2 was recovered from Algeria in 2018 with an original mass of 37.2 g. After examination, it was classified as a recrystallized and equilibrated – petrologic type 6 – ordinary „L" (low-iron) chondrite. This classification, however, is still somewhat contradictory since certain chemical results place the stone in the category of „E" (enstatite) chondrites. Further study is required to get a definitive answer to the anomalous nature of this meteorite. It suffered weak – S3 type – shock metamorphism and moderate – W3 type – weathering, with its terrestrial age ranging between 15 – 30 ka. Following these results, NWA2 received the name of L(?)6S3W3.

Noble gas analysis was performed on two samples for both meteorites via noble gas spectrometry, focusing on isotopic ratios of He, Ne, Ar, and Xe. NWA1 shows a cosmic exposure of ~6.3 million years, which almost perfectly coincides with the cosmic exposure ages of many other known H chondrites, being around 6.5-7 million years. This suggests that NWA1 was ejected at a time when a large impact event happened on the parent body that launched a significant amount of material into space, causing most H chondrites to have similar exposure ages.

NWA2 also shows a cosmic age of ~6 million years. Opposing NWA1, this result cannot be tied to a major impact event happening on either the L, or the E chondrite parent body, suggesting this meteorite to be the result of a smaller scale impact (Wieler, 2002).

References

Wieler R. (2002): Reviews in Mineralogy and Geochemistry, 47(1), 125–170.

Stöffler D., Keil K. & Edward S.R.D. (1991): Geochimica et Cosmochimica Acta, 55(12), 3845–3867.

Van Schmus W.R. & Wood J.A. (1967): Geochimica et Cosmochimica Acta, 31(5), 747–765.

Wlotzka F. (1993): Meteoritics, 28(3), 460.

THE ROLE OF FLUID MOLECULES IN MANTLE MINERAL PHASE TRANSFORMATION

Thomas Pieter Lange[1,2,3]*, Mihály Pósfai[4,5], Péter Pekker[4,5], Péter Vancsó[6], Zakhar Popov[7], Csaba Szabó[1,3], István János Kovács[1] & Márta Berkesi[1,2]

[1] HUN-REN Institute of Earth Physics and Space Science, Sopron, Hungary
[2] MTA-EPSS FluidsByDepth Lendület Research Group, Sopron, Hungary
[3] Eötvös Loránd University, Institute of Geography and Earth Sciences, Lithosphere Fluid Research Lab, Budapest, Hungary
[4] HUN-REN–PE Environmental Mineralogy Research Group, Veszprém, Hungary
[5] University of Pannonia, Research Institute of Biomolecular and Chemical Engineering, Veszprém, Hungary
[6] HUN-REN Centre for Energy Research, Nanostructures Department, Budapest, Hungary
[7] Russian Academy of Sciences, Emanuel Institute of Biochemical Physics, Russia
* E-mail: lange.thomas@epss.hun-ren.hu

Fluid-mediated element transport plays an important role in global element cycling due to the relatively fast migration of intergranular fluids in the Earth's interior (Novella et al., 2024). Fluids are a supercritical state of matter in the Earth's mantle and are composed of element and molecule species that govern fluid properties, influence dissolution, viscosity and surface wetting (Myson, 2022). In addition, the presence of intergranular fluid significantly affects rock rheology via dissolution-reprecipitation creep mechanisms (e.g., Padrón-Navarta & Hidas, 2024).

Among all the mantle fluid species, H_2O has the strongest capacity (Myson, 2022) to dissolve silicate components (e.g., Si), forming hydrated fluid complexes (e.g., $Si(OH)_4$; Newton & Manning, 2008). The hydrated fluid complexes are carried by the H_2O molecules via the interaction between the OH-bonds at the end of the fluid complex and surrounding H_2O molecules (Doltsinis et al., 2007). The molar ratio of bulk H_2O in the solution, including H_2O surrounding the hydrous complex, determines the solubility of the dissolved element (Doltsinis et al., 2007). The dissolution of certain elements (e.g., Al) can be enhanced by the dissolution of other ions (such as Na), where dissolved components form a joint hydrous fluid complex (e.g., Newton & Manning, 2008).

Mineral-fluid interactions in the deep Earth (lower crust and beneath) are mostly described via the simple equation

Solid (1) + Fluid (1) ⍰ Solid (2) + Fluid (2),

in which solid components are described precisely due the known stoichiometry of the solid of interest. In contrast, fluids are described as

- (1) the term 'fluid$_x$', where x is the number of the considered bulk fluid (e.g., fluid$_1$) or
- (2) as fluid (oxide), the oxide of interest (e.g., SiO_2, Na_2O). Alternatively, this term can also be written as 'oxide (fluid)'.

In our study, we propose a new approach to present fluid-solid interaction, in which dissolved molecules are considered in the chemical equations. The novel method provides a more exact description of fluid evolution and allows the incorporation of thermodynamic properties of fluid complexes. The equation will be demonstrated through the fluid-mediated clinopyroxene-to-amphibole phase transformation in the lithospheric mantle (Lange et al., 2023). By using the new approach to describe large-scale processes, such as subduction, we can increase our knowledge of triggering mechanism of sudden events like fluid induces earthquakes such as the once observed in the Vrancea zone.

The study was supported by the LP2022-2/2022 FluidsbyDepth Momentum grant and the Research Grant Hungary (no. 531001) project.

References

Doltsinis N., Buchard M., Maresch W.V., Boese A.D. & Fockenberg T. (2007): Journal of Theoretical and Computational Chemistry, 6(1), 49–62.

Lange T.P., Pálos Zs., Pósfai M., Berkesi M., Pekker P., Szabó Cs. & Kovács I.J. (2023): Lithos, 107210

Myson B. (2022): Progress in the Earth and Planetary Sciences, 9:54.

Padrón-Navarta, H.A. & Hidas K. (2024): EMU Notes in Mineralogy, 21(6), 155–188.

Newton R.C. & Manning C. (2008): Chemical Geology, 249, 250–261.

Novella D., Demouchy S. & Bolfan-Casanova N. (2024): Elements, 20, 235–240.

STRUCTURAL, MAGMATIC AND METALLOGENETIC EVOLUTION OF THE ŠTIAVNICA STRATOVOLCANO

Jaroslav Lexa[1]* & Peter Koděra[2]
[1] Earth Science Institute of the Slovak Academy of Sciences, Bratislava, Slovakia
[2] Comenius University, Department of Mineralogy, Petrology and Economic Geology, Bratislava, Slovakia
* E-mail: jaroslav.lexa@gmail.com

1. Introduction

The Štiavnica Stratovolcano is the most extensive and complex volcanic edifice among the Miocene to Quaternary volcanoes of the Carpathian–Pannonian region that hosts the world-class Banská Štiavnica–Hodruša ore district. It has well-preserved volcanic formations and complexes in the proximal and distal zones that allowed for a serious paleovolcanic reconstruction (Konečný et al., 1998; Chernyshev et al., 2013). A resurgent horst in the central part of its caldera exposes subvolcanic intrusive complexes and related ore mineralizations. Thanks to a detailed geological mapping, extensive past and ongoing mining works, exploration drilling and laboratory investigation of variable mineralization types, there exists a comprehensive data set concerning their geological setting and metallogenesis. Along with new data on timing of the edifice structural evolution (Lexa et al., 2025), its magmatic evolution (Rotier et al., 2020), and genesis of related mineralizations, it opens a way to a fundamental discussion of mutual relationships among structural, magmatic, and metallogenetic processes of a large and complex andesitic volcanic edifice.

2. Structural evolution

As defined by Konečný et al. (1998), the Štiavnica Stratovolcano is a large and complex volcanic edifice (Fig. 1) in the Central Slovakia Volcanic Field that in turn represents a part of the widespread Miocene to Quaternary volcanic formations in the Carpathian–Pannonian region. Volcanic activity was closely related to the tectonic evolution of the region. An interplay of retreating subduction and back-arc extension with related asthenosphere upwelling created conditions for generation of a diverse suite of volcanic rocks dominated by andesites (Harangi et al., 2024 and references therein). The edifice of the Štiavnica Stratovolcano represents a succession of volcanic formations and complexes with a common central zone and outward dipping volcanic slopes that corresponds to the protracted evolution of a transcrustal magmatic system (Rottier et al., 2020). Its structure and evolution in five essential stages has been recently treated by Chernyshev et al. (2013) and Lexa et al. (2025).

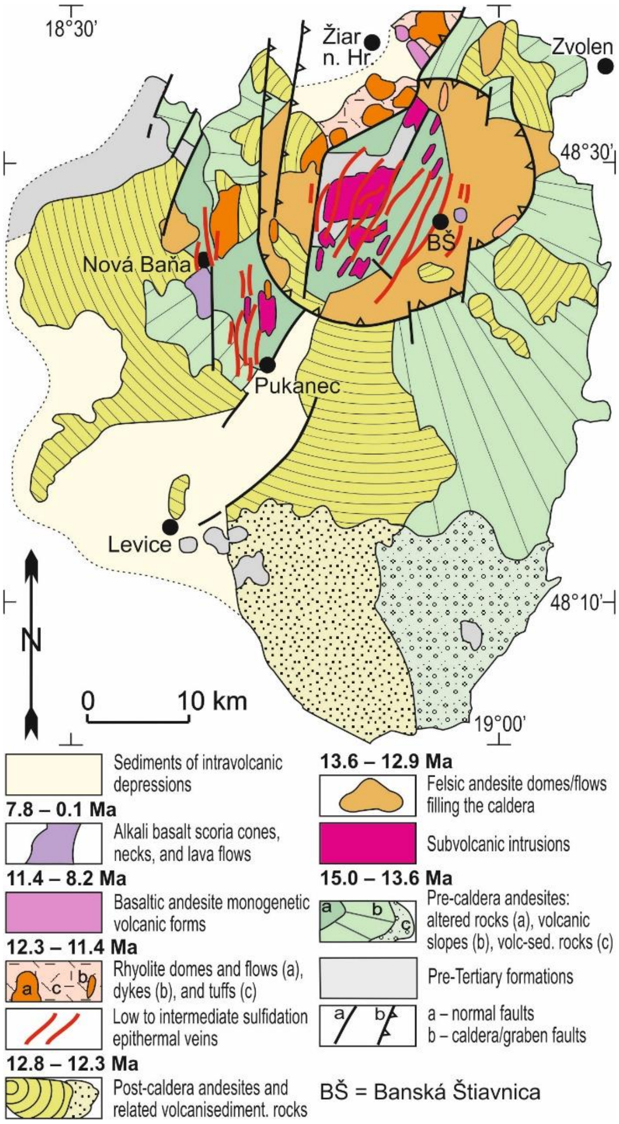


Figure 1. *Scheme of the Štiavnica Stratovolcano edifice with a caldera and a resurgent dome in the central zone. Modified after Chernyshev et al. (2013).*

During the 1st or pre-caldera stage (dated to 15.0–13.6 Ma) volcanic activity of px and amph-px andesites, interrupted by periods of quiescence and related erosion, created a succession of stratovolcanic complexes and formations. Paleovolcanic reconstruction points to remnants of a large stratovolcanic edifice, 40 km in diameter at the base of a compound volcanic cone, surrounded by accumulations of epiclastic volcanic rocks.

In the central zone of the edifice, rocks of the pre-caldera stage are exposed in the eastern half of the resurgent horst (Fig. 1). Here, the former stratovolcanic edifice has been deeply eroded and is built mostly of andesite sills and laccoliths emplaced in the lower part of the edifice. The pre-caldera stage also comprises a stock of bt-amph-px diorite porphyry south of the caldera (~14.5 Ma, stage 1b) that hosts a sub-economic Beluj Au-porphyry mineralization (Kozák et al., 2017).

During the 2nd stage in the evolution of the Štiavnica Stratovolcano edifice (dated to the interval 13.6–12.9 Ma) a break in volcanic activity, extensive denudation in its central zone, and emplacement of subvolcanic/ intravolcanic intrusions took place.

The subvolcanic/intravolcanic intrusive complex is exposed in the uplifted block of the resurgent horst in the central zone of the volcano (Fig. 1). The oldest diorite intrusion (~14.8 Ma) is the parental intrusion of the barren Šobov high-sulfidation hydrothermal system (Lexa et al., 1999b). A younger granodiorite bell-jar pluton (~13.44 Ma, stage 2a) emplaced by the underground cauldron subsidence mechanism invaded basement rocks especially using subhorizontal discontinuities in the Mesozoic sedimentary formations above the Variscan crystalline rocks. Three types of mineralizations are associated with the emplacement of the granodiorite bell-jar pluton (Koděra et al., 1998, 2004, 2021). At contacts of the pluton with basement carbonate rocks there are magnetite skarn deposits and occurrences. In the central part of the pluton the overlying pre-caldera stage andesites are affected by extensive advanced argillic alteration, while underlying granodiorite and fragments of basement rocks host a stockwork-disseminated base metal mineralization.

Kubač et al. (2018) revealed that the extensive denudation was related to a resurgent uplift of the granodiorite pluton and associated sector collapse at the SE side of the edifice in the interval 13.44–13.3 Ma. A basal, low angle detachment/shear zone hosts the Hodruša precious/base metal epithermal mineralization.

Quartz-diorite porphyry sills (stage 2b) invaded major subhorizontal discontinuities in the basement, granodiorite pluton, contact of basement and volcanic complex, and overlying andesites of the pre-caldera stage. Sills emplaced among andesites occur especially in the area of the sector collapse where they intrude structures of the shear zone, both low angle faults as well as moderately dipping tension faults (Kubač et al., 2018). Emplacement of sills (13.3–13.0 Ma) post-dated the precious/base metal mineralization of the shear zone, with the exception of few thin sills parallel with the roof of the granodiorite that were emplaced before the mineralization and the granodiorite pluton emplacement (~13.60 Ma). Further eastward the sills pass into moderately outward dipping ring dikes.

Granodiorite to quartz-diorite porphyry dike clusters and small stocks (~12.9 Ma, stage 2c) are situated at the periphery of the granodiorite pluton. Stocks with roof pendants in basement rocks pass upward into dike clusters emplaced in andesites of the pre-caldera stage. Intrusions of granodiorite porphyry are accompanied by the Cu-Au skarn-porphyry type mineralization (Koděra et al., 2010).

Quartz-diorite porphyry dikes extend in the western and northern parts of the resurgent horst, outside of the sills extent. They are mostly thin, either vertical or dipping inward, showing some aspects of cone sheets. They post-date granodiorite porphyry stocks/dike clusters and quartz-diorite porphyry sills.

During the 3rd or caldera stage (~12.9 Ma) subsidence of the Štiavnica caldera took place. Related volcanic activity filled the caldera and formed contemporaneous volcanic deposits on slopes of the Štiavnica Stratovolcano edifice. The caldera has 20 km in diameter (Fig. 1) and the extent of its subsidence is estimated at 500 m. It is not of an explosive type, but it is filled by bt-amph andesite/dacite extrusive domes, dome flows, and associated pyroclastic and epiclastic volcanic rocks. Tuffaceous sediments at the base of the caldera filling and underlying andesites of the pre-caldera stage are locally affected by advanced argillic alteration showing typical features of hot-spring type systems. Andesites of the caldera fill at its eastern part host a barren Varta high-sulfidation hydrothermal system with advanced argillic alteration (Lexa et al., 1999).

During the 4th or post-caldera stage (12.8–12.3 Ma) a renewed activity of less evolved andesites created explosive, stratovolcanic, and effusive volcanic complexes/formations that rest upon caldera fill and outside of the caldera on slopes of the Štiavnica Stratovolcano edifice. Individual complexes/formations are spatially limited to certain sectors of the edifice. In the distal zone they pass into aprons of epiclastic volcanic breccias, conglomerates, and sandstones.

During the 5th or late stage (12.3–11.4 Ma) rhyolite volcanic activity created dikes, cryptodomes, and extrusive domes on N–S to NE–SW striking faults, including marginal faults of a contemporaneous resurgent horst in the central part of the caldera and local horsts west of the caldera (Fig. 1). An extensive dome/flow complex with related pyroclastic and epiclastic rocks spreads along southeastern and eastern marginal faults of the Žiar depression in the northern sector of the Štiavnica Stratovolcano edifice. Faults of the resurgent horsts host also an extensive system of intermediate to low-sulfidation precious/base metal epithermal veins (Kovalenker et al., 1991; Koděra et al., 2014, 2021; Majzlan et al., 2016, 2018; Vlasáč et al., 2024). The hydrothermal system and rhyolite activity were contemporaneous (Lexa et al., 1999a, 2025).

3. Magmatic evolution

The Central Slovakia Volcanic Field, including the Štiavnica Stratovolcano edifice, shows a close relationship to extension in a back-arc setting. As summarized by Harangi et al. (2024), primary mafic magmas were generated by partial melting of metasomatized lithospheric mantle and/or lower crustal metabasic source in association with tectonothermal rejuvenation related to the extension-induced asthenospheric upwelling. Magmas evolved further via a high-pressure fractionation and/or lower crustal assimilation and hybridization in a deep crustal hot zone towards more silicic compositions. Rottier et al. (2020) documented that further evolution of magmas feeding the Štiavnica Stratovolcano edifice took place in a transcrustal magmatic system. As evidenced by interpreted pressures between ~1 and ~3 kbar (Table 1), volcanic and intrusive rocks of the edifice had their source in an upper crustal magma reservoir at a depth of 4–12 km. Dominantly silicic composition of melt inclusions and thermometry indicate that the different phenocrysts have crystallized from dacitic to rhyolitic residual melts at a temperature between ~960 and ~700 °C. A clear change of mineralogy from plg-opx-cpx through plg-opx, plg-opx-amph, and plg-amph-bt to the final plg-amph-bt-qtz is observed with a decrease of magma temperature. With the exception of most evolved rocks (subvolcanic intrusions, caldera fill, and late stage rhyolites) matrix composition of andesites is substantially less silicic than melt inclusions in phenocrysts. The frequent presence of mafic enclaves, disequilibrium phenocrysts assemblages, and resorbed cores of phenocrysts indicate that the evolved crystal-rich magmas were mixed with more mafic magmas ascending from a deeper source. A direct evidence for a magma evolution in the middle crustal reservoir is provided by the pressure and temperature of mafic Cr-rich cpx phenocrysts in the opx-cpx andesites, indicating pressure and temperature conditions of 3.7–5.3 kbar and 1130 to 1170 °C, respectively (Table 1).

Apparently, it was the extent of mafic magma input into the upper-crustal crystal mush that has governed the composition of erupting magmas. A large input of mafic magma lead to eruptions of px and px-amph andesites with less silicic matrixes, while during periods of a lesser mafic magma input the erupting magma composition was governed by magma evolution towards more silicic and volatiles-enriched composition. The crystal assemblage of the Beluj diorite porphyry, characterized by magmatic garnet, high-Al+Mg-amph, Cr-rich cpx, opx and plg, suggests a mixing of magmas sourced from three levels of crystallization (lower-, middle-, and upper-crustal).

Late-stage rhyolites show the same composition as silicate melt inclusions in phenocrysts of other rocks. Thus, they represent a segregation of the interstitial silicic melt from the crystal mush during its cooling below 750 °C, leading to the formation of eruptible rhyolite magma pockets.

Mineralizations of the Štiavnica Stratovolcano edifice are genetically associated with those magmas that evolved by a prolonged cooling of the upper crustal crystal mush and related fluid saturation (stages 2, 3, and 5). Cooling and perhaps also magma mixing that led to the fluid saturation and exsolution from the long-lived crystal mush were the key factors in the formation of the different ore deposits. In contrast, the source magma of the Beluj Au-porphyry system resulted from mixing between a deep and hydrous magma and an evolved, dry, upper crustal crystal mush.

Table 1. *Summarized P-T-X parameters of rocks of the Štiavnica Stratovolcano edifice (Rottier et al., 2020)*

Stage	SiO_2 (wt.%) Whole-rock	SiO_2 (wt.%) Matrix	SiO_2 (wt.%) Melt inclusions	Pressure (kbar)	Temperature (°C)
5	72.2–77.7	76–77	71–80	2.9–3.2	700–760
4	56.1–63.5	66.5–78.1	70–78 (63–68)	1–3, *~4.2**	770–860, *~910**
3	59.0–66.6	74–78	70–78	1.7–2.9	730–820
2c	60.02–63.4	Eutectic Qtz-Kfs-Pl	73–79	1.5–3.0	720–810
2b	62.73–64.46	Eutectic Qtz-Kfs-Pl	73–81	~2.7	~770
2a	60.2–64.7	Eutectic Qtz-Kfs-Pl	71–81	2.0–3.3	740–820
1b	58.0–61.0	59–63	74–77	2.1–3.0, *3.7–6.1**	795–880, *~1135**
1	55.6–61.5	68.3–71.1	Mostly 70–80	0.7–2.2	750–860

**interpreted pressure and temperature of Cr-rich cpx phenocrysts in the opx-cpx andesites*

4. Related mineralizations

The Štiavnica Stratovolcano edifice hosts numerous intrusion-related magmatic-hydrothermal as well as extensive epithermal precious/base metal mineralizations. Occurrences of individual mineralization types with their geologic setting are mentioned in the section 2 concerning structural evolution of the edifice, along with relevant references. Their essential aspects are summarized in Table 2.

Table 2. *Mineralizations of the Štiavnica Stratovolcano edifice (references are in the sections 2 and 5)*

Stage	Mineralization	Geology/Structure	Minerals	Alteration	Fluids
1	Šobov high-sulfidation epithermal system	Metasomatic silicite surrounded by argillites in andesites above the parental diorite intrusion	Qz, Prl, Dsp, Py	Advanced argillic	Low salinity acid fluids, condensation of magmatic vapor
1b	Beluj Au-porphyry mineralization	Stockwork of Mag-Bt and Qz veinlets in a shallow px-amph diorite stock	Au, Mag, Bt, Qz	K-silicate with intermed. argillic overprint	High-T magmatic fluids split into salt melt and vapor
2a	Magnetite skarn mineralization	Irregular Mag lenses in Ca-Mg skarns at the contact of granodiorite and limestones/dolomites	Mag, Grt, Di, Wo, Ep, Tr, Adr	Ca-Mg skarns, metasomatic overprint	Brine cooling and mixing with meteoric water
	Advanced argillic alterations	Metasomatic silicite and argillites in andesites above the parental granodiorite pluton	Qz, Prl, Kln, Py, Ant, Tpz	Advanced argillic	Low salinity acid fluids, condensation of magmatic vapor
	Stockwork/ disseminated base metal mineralization	Contraction cracks in apical parts of the granodiorite pluton + basement carbonate rocks replacement	Sp, Gn, Ccp, Py, Qz, Ep, Ab	Chl, Ep, Kfs, Ab, Ilt	Ascent of exsolved supercritical fluids – mixing of magmatic and meteoric fluids
2a / 2b	Hodruša precious/base metal epithermal mineralization	Hosted by a shear zone at the base of a sector collapse above the granodiorite pluton, hydraulic fracturing followed by extension fractures of the shear zone	Au, Sp, Gn, Ccp, Py, Qz, Rdn, Rds, Chl	Ad, Qz, Ilt + intermediate argillic in hanging wall andesites	Ascent of exsolved supercritical fluids – cooling and boiling of magmatic fluid due to decompression
2c	Cu-Au skarn-porphyry type mineralization	Veinlets, massive or disseminated in Ca-Mg exo- and endo-skarns that are hosted by roof pendants of carbonate rocks engulfed by granodiorite porphyry	Au, Ccp, Py, Pyh, Mol, Mag, Hem, Ep, Qz,	Ca- Mg skarns + K-silicate, phyllic, argillic and propylitic zones	Early brine and vapor, later single phase magmatic fluid mixed with meteoric water
3	Hot-spring type systems	Metasomatic silicites and argillites in tuffaceous sediments and underlying andesites at the base of the caldera filling, tops of boiling hydrothermal systems?	Opl, Kln, Py, Alu; deeper Qz, Kln, Py, Sm, Ilt	Advanced argillic, downward intermediate argillic	Steam-heated, vapor condensation and H_2S oxidation at the ground water level
	Varta high-sulfidation hydrothermal system	Metasomatic silicite surrounded by argillites in andesites of the caldera filling, probably related to a parental quartz-diorite stock	Qz, Kln, Py; Kln, Ilt/Sm, Py	Advanced argillic	Low salinity acid fluids, condensation of magmatic vapor
5	Intermediate/low-sulfidation precious/base metal epithermal veins	Hosted by faults of the resurgent horst in the caldera center, above a cupola of saturated rhyolitic magma	Sp, Gn, Ccp, Py, Mc, Ag-sulfosalts, Ttd, Ac	Ad, Qz, Ilt, Ilt/Sm, Py	Long lasting exsolution of supercritical fluids, their boiling and mixing with meteoric fluids

5. Fluids evolution

The Šobov high-sulfidation epithermal system experienced two stages of fluid evolution, including condensation of magmatic vapor in andesite, resulting in acid leaching at >270 °C and later penetration of fluids predominantly of meteoric origin (250–270 °C, 0–3 wt.% NaCl eq., >660 m depth; Oružinský & Hurai, 1985).

The Au-porphyry mineralization at Beluj formed from Au-bearing Fe-K-Na-rich salt melts of high temperatures (>600°C) and extremely low-density vapors, typical for shallow Au-porphyry systems (Kozák et al., 2017).

Granodiorite pluton related to Fe-skarns and base metal stockwork mineralization produced fluids that experienced heterogenization into a hot hypersaline brine and vapor (>600°C; Koděra et al., 2004). Skarn mineralization was produced from brines (up to 71 wt.% NaCl eq.) mixed with meteoric water (215°–370°C) and advanced argillic alteration above the apical part of the granodiorite pluton originated from condensed vapor (191–367 °C). Base metal stockwork mineralization crystallized from fluids showing positive correlation of salinity (5–0.5 wt.% NaCl eq.) and temperature (330–190 °C), indicative for mixing of fluids, also confirmed by combined O and H isotope data. The absence of boiling explains the absence of gold in ores.

Fluids related to gold-rich shear zone-hosted veins are of moderate temperature (~250–310 °C, 1–4 wt.% NaCl eq.) with evidence of boiling, induced by decompression evolving from suprahydrostatic to hydrostatic conditions at a depth of ~550 m (Koděra et al., 2005, 2019). Boiling was responsible for gold precipitation and it was related to opening of dilatational structures within the shear zone that enabled an active suction of fluids and their decompression.

In Cu-Au skarn-porphyries, studied at the Vysoká-Zlatno deposit (Koděra et al., 2010), early batches of magmatic fluids have experienced fluid immiscibility prior to reaching the skarn–porphyry level and produced liquids of different salinity and low salinity vapor (up to 575 °C, 70 wt.% NaCl eq.). Late magmatic low-salinity single phase fluids (323–364 °C, <3 wt.% NaCl eq.) are responsible for the precipitation of sulfidic ore.

Advanced argillic alteration in the caldera fill were produced by ancient hot springs, corresponding to steam-heated fluids, resulting from deeper boiling of hydrothermal fluids and vapor condensation at the ground water level (Onačila et al., 1995).

High-sulfidation hydrothermal system at Varta results from boiling fluids (200–300 °C, <2.7 wt.% NaCl eq.) and their condensation in several hundred-meter depth (Oružinský & Hurai, 1985).

Fluid inclusions in the base metal horst veins have wide ranges of salinity and temperatures (0.5–11.5 wt.% NaCl eq., 360–110 °C) with evidence for fluid boiling and mixing (Kovalenker et al., 1991).

According to LA-ICP-MS analyses of fluid inclusions by Koděra et al. (2021), fluids related to the base metal stockwork and all epithermal mineralizations show increased B, As, and Sb contents which indicates that the fluid source was a supercritical magmatic fluid contracted to liquid during ascent from the crystallizing magma chamber. Their relatively constant composition (including metals) and high Cs contents indicates exsolution from an evolved interstitial melt of roughly constant composition. This is consistent with the stable composition of evolved melt inclusions in rock-forming minerals (e.g., B/Rb, Rb/Cs), representing the residual melt in upper crustal reservoir during different stages of magmatic activities (Rottier et al., 2020).

6. Metallogenetic evolution

According to Rottier et al. (2020), the magmas and all mineralizations of the Štiavnica Stratovolcano edifice were sourced from an upper crustal reservoir (1 to 3 kbar at 860 to 700 °C) that was active for more than 3 million years. Ore deposits formed primarily during periods of reservoir cooling when the residual evolved melt reached fluid saturation. However, there are two exceptions concerning early intrusion-related mineralizations (~14.8 and ~14.5 Ma). The Šobov system was related to intermediate diorite magma that reached saturation only upon a high-level emplacement. The Beluj diorite porphyry hosting Au-porphyry system resulted from a mixing between a deep and hydrous magma and an evolved, dry, upper crustal crystal mush.

Subsequent mineralizations were related to the emplacement of evolved subvolcanic intrusions and corresponding processes in the magma reservoir and structural evolution. The emplacement of granodiorite magma between the pre-volcanic basement and pre-caldera andesites at a minimum depth of ~2 km created an extensive bell-jar pluton (~13.44 Ma). Its emplacement was compensated by a descent of the central block of basement rocks into the upper crustal magmatic reservoir. Upon cooling and progress of crystallization, exsolution of fluid appeared that was responsible for the Fe-skarn mineralization at contacts of the granodiorite with limestones (brine) and advanced argillic alteration in overlying andesites (vapor).

In the reservoir, cooling and possibly mixing of the magma led to the saturation of fluids. Their initial exsolution and ascent led to the origin of the base metal stockwork mineralization close to the roof of the granodiorite pluton affected by contraction cracking.

Exsolution of fluids also led to a decrease in magma density followed by its migration and emplacement between the subsiding basement block and the already solidified granodiorite pluton. Related magma decompression, in turn, accelerated the fluid exsolution lowering further its density. This low-density magma with exsolved fluids was responsible for a rapid isostatic exhumation of the granodiorite pluton, finally leading to a sector collapse of the volcano, at the base with a flat shear zone hosting the epithermal gold-rich veins, supplied by fluids from the saturated magma bellow the granodiorite. The accumulation of evolved magma of lower density in the magmatic reservoir finally led to the emplacement of the system of post-mineralization quartz-diorite porphyry sill and dykes of (13.3–13.0 Ma), especially using the structures of the shear zone, and termination of the hydrothermal activity.

Further evolution of magma in the reservoir by periods of cooling alternating with events of recharge led at first to the emplacement of granodiorite porphyry stocks and dike clusters around the granodiorite pluton (~12.9 Ma) and finally to the caldera subsidence (~12.9 Ma). Cu-Au porphyry-skarn systems were fed by fluids migrating through the hot porphyry stocks, while fluids of the caldera hosted hot-spring systems and Varta high sulfidation system represented fluids migrating along faults and issued by a porphyry stock, respectively.

A dominantly effusive activity of less evolved and hotter (up to 860 °C) andesitic magmas, following the caldera subsidence (12.8–12.3 Ma), reflected probably large inputs of mafic magma into the upper-crustal reservoir. A final cooling of the reservoir (<750 °C) had created conditions for a segregation of fluid-saturated rhyolite magma that accumulated in a cupola. Again, the decrease in magma density due to fluid exsolution resulted in the uplift of the resurgent horst in the center of the caldera. The horst related extension faults mediated emplacement of rhyolite dikes and domes as well as migration of exsolved fluids that created an extensive system of epithermal veins (12.3–11.4 Ma).

During the evolution of the parental magma reservoir/chamber fluids were continuously exsolved and accumulated but liberated during periods of tectonic events. These include migration via contraction fractures (Pb-Zn-Cu stockwork in granodiorite), ring fractures, and shear zone induced by a sector collapse of the volcano (early Au-Ag-Pb-Zn-Cu veins), along with porphyry stocks (Cu-Au skarn-porphyries), and faults of a resurgent horst uplift (late Ag-Au-Pb-Zn-Cu veins). Ore precipitation was triggered by mixing magmatic and meteoric water (stockwork), boiling of decompressed fluids (early veins), cooling of contracted vapor affected by early fluid heterogenization (skarn-pophyries), and mixing+boiling (late veins). Thus, external factors, rather than fluid compositions, controlled primarily the different metal endowment of these mineralizations.

Acknowledgements

This work was supported by grants VEGA No. 1/0313/20, APVV-15-0083, APVV-22-0134 and the company Slovenská banská, Ltd.

References

Chernyshev I.V., Konečný V., Lexa J., Kovalenker V.A., Jeleň S., Lebedev V.A. & Goltsman Y.V. (2013): Geologica Carpathica, 64, 327–351.

Harangi Sz., Seghedi I. & Lukács R. (2024): Geological Society, London, Special Publications, 554., 1–46.

Koděra P., Lexa J., Rankin A.H & Fallick A.E. (2004): Economic Geology, 99, 1745–1770.

Koděra P., Lexa J. & Fallick A.E. (2010): Mineralium Deposita, 45, 817–843.

Koděra P., Lexa J., Fallick A.E., Wälle M. & Biroň A. (2014): Geological Society, London, Special Publications, 402, 177–206.

Koděra P., Kubač A., Lexa J, Rottier B. & Laurent O. (2021): Proceedings 16th Biennial SGA Meeting, 2, 96.

Koděra P., Lexa J., Chovan M., Vojtko R., Kubač A., Rottier B., Rybárik M. & Prcúch J. (2023): Proceedings 17th Biennial SGA Meeting, 2, 147–150.

Konečný V., Lexa J., Halouzka R., Hók J., Vozár J., Dublan L., Nagy A., Šimon L., Havrila M., Ivanička J., Hojstričová V., Mihaliková A., Vozárová A., Konečný P., Kováčiková M., Filo M., Marcin D., Klukanová A., Liščák P. & Žáková E. (1998): Explanations to the geological map of the Štiavnické vrchy and Pohronský Inovec Mts. (Štiavnica Stratovolcano). Geological Survey of Slovak Republic, Bratislava.

Kovalenker V.A., Jeleň S., Levin K.A., Naumov V.B., Prokof'ev V.J. & Rusinov V.L. (1991): Geologica Carpathica, 42, 291–302.

Kozák J., Koděra P., Lexa J., Bakos F., Molnár L. & Wälle M. (2017): Acta Geologica Slovaca, 9, 45–61.

Kubač A., Chovan M., Koděra P., Kyle J.R., Žitňan P., Lexa J. & Vojtko R. (2018): Mineralogy and Petrology, 112, 705–731.

Lexa J., Štohl J. & Konečný V. (1999a): Mineralium Deposita, 34, 639–654.

Lexa J., Štohl J. & Žáková E. (1999b): In: Molnár F., Lexa J. & Hedenquist J.W. (eds.): Epithermal mineralization of the Western Carpathians. SEG Guidebook Series, 31, 259–264.

Lexa J., Yi K., Broska I., Cieselska Z., Koděra P., Kohút M., Mathur R., Prcúch J., Szczerba M., Uhlík P. & Vojtko R. (2025): Geologica Carpathica, 76, 1–24.

Majzlan J., Berkh K., Koděra P., Števko M., Bakos F. & Milovský R. (2016): Acta Geologica Slovaca, 8, 133–147.

Majzlan J., Berkh K., Kiefer S., Koděra P., Fallick A.E., Chovan M., Bakoš F., Biroň A., Ferenc Š. & Lexa J. (2018): Mineralogy and Petrology, 112, 1–23.

Onačila D., Lexa J., Marsina K., Rojkovičová Ľ., Káčer Š., Hojstričová V., Žáková E., Štohl J., Konečný V., Nemčok M., Koděra P., Konečný P., Repčok I., Hurai V., Háber M., Jeleň S., Maťo Ľ., Sasvári T., Schmidt R., Zvara I. & Grant T (1995): Metallogenentic model and resource assessment in the Štiavnica Stratovolcano central zone (in Slovak). Open file report, Archive *ŠGÚDŠ*, Bratislava.

Oružinský V. & Hurai V. (1985): Mineralia Slovaca, 17, 415–425.

Rottier B., Audetat A., Koděra P. & Lexa J. (2020): Journal of Volcanology and Geothermal Research, 401, 106967

Vlasáč J., Mikuš T., Majzlan J., Števko M., Biroň M., Szczerba M., Milovský R. & Žitňan P. (2024): Journal of Geosciences, 69, 21–47.

ZIRCON FINGERPRINTING REVEALS THE MAGNITUDE, TEMPO AND SIZE OF EARLY TO MID-MIOCENE EXPLOSIVE VOLCANISM IN THE PANNONIAN BASIN

Réka Lukács[1], Mihovil Brlek[2], Nina Trinajstić[2], Razvan Bercea[3,4], Samuel Rybár[5,6], Katarína Šarinová[7], Viktória Subová[5], Slavomír Nehyba[8], Péter Gál[1], János Szepesi[1,9], Krisztina Sebe[10], Sándor Józsa[11], Jörn-Frederik Wotzlaw[12], H. Albert Gilg[13], Marcel Guillong[12], Maxim Portnyagin[14], Maurizio Petrelli[15], Sean P. Gaynor[16], Dawid Szymanowski[12], Olivier Bachmann[12], Szabolcs Harangi[1,11]

[1] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[2] Croatian Geological Survey, Department of Geology, Zagreb, Croatia
[3] Babeș-Bolyai University, Department of Geology, Cluj-Napoca, Romania
[4] S.N.G.N. Romgaz S.A., Tîrgu-Mureș, Romania
[5] Comenius University, Department of Geology and Paleontology, Bratislava, Slovakia
[6] Technical University of Ostrava, Department of Geodesy and Mine Surveying, Ostrava Poruba, Czech Republic
[7] Comenius University, Department of Mineralogy, Petrology and Economic Geology, Bratislava, Slovakia
[8] Masaryk University, Brno, Czech Republic
[9] HUN-REN Institute for Nuclear Research, Debrecen, Hungary
[10] HUN-REN-MTM-ELTE Research Group for Paleontology, Budapest, Hungary
[11] Eötvös Loránd University, Deptartment of Petrology and Geochemistry, Budapest, Hungary
[12] ETH Zürich, Zürich, Switzerland
[13] Technical University of Munich, School of Engineering and Design, Engineering Geology, Munich, Germany
[14] GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
[15] University of Perugia, Department of Physics and Geology, Perugia, Italy
[16] U.S. Geological Survey, Geology, Geophysics, and Geochemistry Science Center, Denver, USA
* E-mail: lukacs.reka@csfk.org; reka.harangi@gmail.com

Field and borehole data combined with zircon U–Pb geochronology from northern to northeastern Hungary have revealed multiple >100 km³ explosive volcanic eruptions during the Early to Mid-Miocene, sourced from the southern vicinity of the Bükkalja Volcanic Field (BVF; 18.1–14.4 Ma) and from the Tokaj Mountains (13.1–11.6 Ma). Zircon and volcanic glass geochemistry enable the long-distance correlation of volcanic units, even if primary textures are obscured, due to significant geochemical heterogeneities, such as a range of > 10 εHf in zircon and ~5 in La/Nb in volcanic glass. Using this approach, eruptions from the BVF were correlated with distinct ash beds preserved in the La Vedova section near Ancona, Italy. This continuous, orbitally-tuned Langhian to Messinian sequence contains ash layers that temporally and geochemically match five major eruptive units from the BVF and associated centers, such as the Kuchyňa Tuff. Variably altered correlative ash layers across Central and Southern Europe further suggest ash fallout dispersal exceeding 1,000 km. Several eruptions were likely caldera-forming, indicated by thick, continuous volcaniclastic sequences in proximal settings. These findings demonstrate that the Early to Mid-Miocene explosive volcanism in the Pannonian Basin was more extensive than previously recognized. This has major implications across Central and Southern Europe for paleogeographic reconstructions, the evolution of sedimentary basins, and the regional tephrochronological framework. Furthermore, distal tephra occurrences indicate more frequent eruptions from the BVF than previous observed, indicating a faster volcanic tempo than initially thought.

UNIFIED MODEL OF THE METAMORPHIC BASEMENT OF THE SOUTHERN GREAT PLAIN

Tivadar M. Tóth*, Henrietta Kondor, Ábel Polyák
University of Szeged, Department of Geology, Szeged, Hungary
* E-mail: mtoth@geo.u-szeged.hu

The buried metamorphic highs that separate the deep basins forming the basement of the Southern Great Plain (Szeged, Makó-Hódmezővásárhely, Békés Basins) present an opportunity to study the development of the basement. From the west, we examined the Dorozsma (DH), Algyő-Ferencszállás-Kiszombor (AFKH), and Pusztaföldvár (PH) highs in sequence. In previous years, we presented the results of these analyses separately, allowing the creation of a unified structural model.

Early results regarding the structure of the AFKH, which forms the central element of the sample area, are contradictory in many aspects. Some interpretations suggest that the structures of the AFKH and DH are uniform and propose a counterclockwise metamorphic P-T evolution (kyanite after andalusite) with a medium metamorphic Tmax. Other models describe a low-grade metamorphic block in the central part of the AFKH and assume a clockwise evolution for the surrounding medium-grade block. This P-T path does not reach the andalusite stability field. No petrological studies have been conducted on PH for four decades, and those results confirm a uniform, staurolite-zoned MT metamorphic evolution.

Detailed petrographic and thermobarometric analysis of all available drill cores confirmed the existence of the central low-grade block in the AFKH and demonstrated that it can be divided into two subunits with markedly different development. While the epidote orthogneiss exhibits a retrograde P-T path, the chlorite schist block displays a progressive, greenschist facies peak. The MT gneiss block, which constitutes the main part of the AFKH, can be subdivided into three units with distinct histories. All the garnet-kyanite, garnet biotite, and pseudomorph-bearing gneiss realms exhibit a two-phase metamorphic evolution, with an early regional (M1) event followed by a later contact metamorphic one (M2). Based on earlier geochronological data, a Variscan M1 phase was succeeded by an Alpine overprint (M2). Since the physical (P-T) conditions during the M1 and M2 events also differ significantly among the three blocks, they probably represent different depth intervals within the former lithosphere. In the AFKH region, the spatial separation of the five blocks (two low-grade, three medium-grade) was confirmed through detailed mapping and analysis of borehole geophysical data (NGR).

The DH to the west comprises AFKH garnet-kyanite gneiss, displaying consistent M1-M2 development. However, the deepest drillings of DH uncover low-grade dolomite marble, and further down, a block predominantly consisting of medium-grade amphibolite. Borehole geophysical data also corroborate the spatial relationship among the three DH blocks. To the east, the PH area is formed entirely of garnet biotite gneiss identified from AFKH, confirming similar M1-M2 development.

In summary, the amphibolite block found at the lowest structural level on the DH is separated by a thin dolomite marble horizon from the MT gneiss body, which characterises the entire study area and is the most typical rock type of the Southern Great Plain basement. Consistent with previous literature, we link the activity responsible for the M2 contact metamorphic event to Late Cretaceous banatite magmatism. Therefore, we believe that the boundaries of the various M2-developed blocks are defined by younger structures, probably formed during the subsidence of the Pannonian Basin. The structural relationship between the low-grade blocks at the highest topographical position on the AFKH and the MT gneiss terrain remains unclear.

CARBON ISOTOPE CHEMOSTRATIGRAPHY OF THE JENKYNS EVENT IN HUNGARY

Tamás Müller[1]*, József Pálfy[2]
[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[2] Eötvös Loránd University, Department of Geology, Budapest, Hungary
* E-mail: beregond02@gmail.com

In the early Toarcian (Early Jurassic, ca. 183 Ma), a series of Earth system-wide environmental changes occurred affecting all exospheres, commonly referred to as the Jenkyns Event (also known as the Toarcian Oceanic Anoxic Event) (Jenkyns, 2010; Müller et al., 2017). The concomitant main activity phase of the Karoo & Ferra large igneous provinces (LIP) suggests a triggering mechanism closely linked to extensive volcanism and associated greenhouse gas emission. This phenomenon led to global warming, seawater pH decline, hydrological cycle acceleration, enhanced continental weathering, increased primary productivity and seawater anoxia, all leading to a second-order mass extinction affecting both marine and terrestrial biota (Pálfy & Smith, 2000; Jenkyns, 2010; Müller et al., 2020).

As a consequence of the disruption of biogeochemical systems, the Jenkyns Event is accompanied by global carbon cycle perturbations, which are recognised worldwide in the sedimentary record. A long positive carbon isotope excursion (CIE), as an indicator of enhanced organic carbon burial, extends throughout the entire early Toarcian. The culmination of the Jenkyns Event is characterised by a large negative CIE by 5-6 ‰, interrupting the positive one, indicating the input of a substantial amount of ^{12}C into the global carbon cycle (Müller et al., 2020). The negative CIE is most commonly associated with sill intrusions in the extensive coal deposits of the Karoo Basin (McElwain et al., 2005). These CIEs and their trends are preserved in marine abiotic and biogenic carbonates as well as in marine and terrestrial organic matter. Using high-resolution carbon isotope data for chemostratigraphy enables the accurate correlation of lower Toarcian successions and allows the compilation of integrated stratigraphic frameworks (Ruebsam & Al-Husseini, 2020).

Lower Toarcian sediments in Hungary are well known and widely studied in the Mecsek and Bakony Mts. and the Gerecse Hills. Published carbon isotope data are also available for several sections (e.g., Jenkyns et al., 1991; Varga et al., 2007; Polgári et al., 2016; Müller & Pálfy, 2024). In the Mecsek, a continuous record of the Jenkyns Event occurs, represented by a ~13m thick black shale, accompanied by very negative organic carbon isotope values typical for the peak of the negative CIE. While in the Bakony Mts. and Gerecse Hills, the lower Toarcian successions exhibit variable lithologies and thicknesses. These include extensive manganiferous and black shale-bearing records in Úrkút (Bakony Mts.) and condensed/hiatal limestones, marls, and rarely thin black shales in the Gerecse Hills. Organic and carbonate carbon isotope records of these occurrences exhibit a negative CIE in the black shale facies, and commonly, the falling limb of the positive CIE is recognised in the limestone-marl facies. Correlation of the Hungarian records of the Jenkyns Event to chemostratigraphic schemes based on composites of multiple lower Toarcian carbon isotope records revealed several details (see Müller & Pálfy, 2024): 1) Black shale deposition in the Mecsek Mts. was continuous, and the completeness of the record is remarkable compared to the extensively studied Toarcian successions elsewhere. This highlights the potential for further studies, such as cyclostratigraphic analyses. 2) The lower manganiferous interval in Úrkút might be older, deposited during the earliest Toarcian. 3) In the Gerecse Hills, the successions are extremely condensed, with significant gaps of 1–2 Myr. This indicates that only the late phase of the Jenkyns Event is preserved.

References

Jenkyns H.C., Géczy B. & Marshall J.D. (1991): The Journal of Geology, 99, 137–149.

Jenkyns H.C. (2010): Geochemistry, Geophysics, Geosystems, 11(3), Q03004

McElwain J.C., Wade-Murph, J. & Hesselbo S.P. (2005): Nature, 435, 479–482.

Müller T., Price G.D., Bajnai D., Nyerges A., Kesjár D., Raucsik B., Varga A., Judik K., Fekete J., May Z. & Pálfy J. (2017): Sedimentology, 64, 66–86.

Müller T., Karancz S., Mattioli E., Milovský R., Pálfy J., Schlögl J., Segit T., Šimo V. & Tomašových A. (2020): Global and Planetary Change, 195, 103366

Müller T. & Pálfy J. (2024): Bulletin of the Hungarian Geological Society, 154, 149–168.

Pálfy J. & Smith P.L. (2000): Geology, 28, 747–750.

Polgári M., Hein J.R., Bíró L., Gyollai I., Németh T., Sajgó C., Fekete J., Schwark L., Pál-Molnár E., Hámor-Vidó M. & Vigh T. (2016): Palaeogeography, Palaeoclimatology, Palaeoecology, 459, 99–120.

Ruebsam W. & Al-Husseini M. (2020): Gondwana Research, 82, 17–336.

Varga A., Raucsik B., Hámoriné Vidó M. & Rostási Á. (2007): Bulletin of the Hungarian Geological Society, 137, 449–472.

MAPPING OF METAVOLCANICS IN THE SOUTHEASTERN PART OF THE BÜKK MTS., HUNGARY

Norbert Németh*, Csilla Balassa
University of Miskolc, Faculty of Earth and Environmental Sciences, Miskolc, Hungary
* E-mail: norbert.nemeth1@uni-miskolc.hu

The Paleo-Mesozoic rocks of the Bükk Mts. can be divided into several structural units (nappes or fault blocks bordered by steep strike-slip zones) comprising more or less different stratigraphic successions. In the southern part of the Mts. the Southeastern Bükk Unit (SU) can be outlined stratigraphically as a tectofacies of the Paraautochthonous succession with outcrops of Middle-Upper Triassic carbonate dominated formations. The most typical feature of this tectofacies is the widely distributed alteration of the pure carbonates to saccharoidal dolomite. On the southwest, SU is largely covered by the Szarvaskő Nappe system. In the southeast, it is bordered by the Central Bükk Unit (CU) on the N and NW side and covered by Cenozoic sediments and volcanics on the S and E side in the continuation towards the Bükkalja region.

The border zone with CU is rather fragmented tectonically. The metavolcanics outcrops are located mostly in this zone. In an earlier study we identified rock bodies of the Szentistvánhegy Metavolcanics in the SU and Szinva Metabasalt in the CU (Németh et al. 2023a) based on trace element composition, but there are bodies as well where a metasomatic alteration with HFSE enrichment overprinted these signatures (Németh et al. 2023b). In contrast with the thick stratovolcanic sequence known in the North, the Szentistvánhegy Metavolcanics of the SU represent distal volcanic facies embedded in basin and platform carbonates.

During the sampling it became obvious that existing maps do not show the outcrops correctly, some of which are of small extents with steeply dipping, a few meters thick layers only, completely under soil cover in most places. While formerly known larger outcrops were mostly basaltic-andesitic, several newly found ones proved to be more differentiated and probably of pyroclastic origin. Due to their relatively high thorium content, a scintillation detector measuring the gamma radiation was used as an aid for mapping. Here we present the actual stage of the knowledge on the occurrence, structural position and composition of the metavolcanics and associated rocks in the Southeastern Bükk area.

References

Németh N., Kristály F., Gál P., Móricz F. & Lukács R. (2023a): International Journal of Earth Sciences, 112, 297–320.

Németh N., Kristály F. & Balassa Cs. (2023b): Journal of Geochemical Exploration, 246, 107159

METASTABLE ARAGONITE FORMATION

Péter Németh[1,2]*, Attila Demény[1], Péter Pekker[2], Aleksander Rečnik[3], Vesna Ribić[3], Pavel N. Gavryushkin[4], Marco Bruno[5], Christoph Spötl[6], Michael Pettauer[7], Martin Dietzel[7], Levente Illés[8] & Mihály Pósfai[2]

[1] HUN-REN REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[2] University of Pannonia, Research Institute of Biomolecular and Chemical Engineering, Veszprém, Hungary
[3] Jožef Stefan Institute, Department for Nanostructured Materials, Ljubljana, Slovenia
[4] Siberian Branch of Russian Academy of Sciences, V.S. Sobolev Institute of Geology and Mineralogy, Novosibirsk, Russia
[5] University of Turin, Department of Earth Sciences, Turin, Italy
[6] University of Innsbruck, Institute of Geology, Innsbruck, Austria
[7] Graz University of Technology, Institute of Applied Geosciences, Graz, Austria
[8] HUN-REN Centre for Energy Research, Institute of Technical Physics and Materials Science, Budapest, Hungary
* E-mail: nemeth.peter@csfk.org

Aragonite is a calcium carbonate polymorph, which is metastable in ambient conditions. Yet, it abundantly crystallizes in the ocean and under certain conditions on the continent. It is also an important biomineral and is the major skeletal material of mollusks, corals and stromatolites. Aragonite deposited on calcite is often observed in sediments and sedimentary rocks. In our presentation, we address this contradiction by studying the crystal structure of calcite-aragonite from ~20,000-year-old samples that formed at 25 °C in the Berger-Károly cave in Tapolca, ~14,000-year-old specimens that formed at 12 °C in fractures of the Sonnenberg (Italy), and modern (5-year-old) deposits from the Erzberg (Austria), which formed at 5 °C.

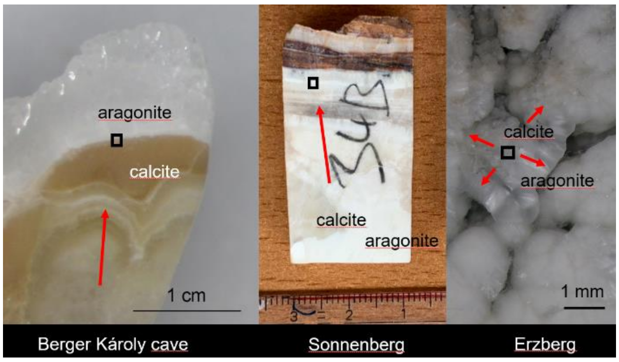


Figure 1. *Optical microscope images of the studied samples. Black rectangle shows the investigated areas and red arrows point to the growth direction.*

Samples were carefully selected to allow identification of the growth direction, as well as the last-formed calcite and the first-formed aragonite on calcite (Fig. 1). We found that the last-formed calcite contained some Mg (Mg/Ca ~0.04 mol%), whereas the first-formed aragonite was Mg-free. To investigate the crystal structure of these carbonates, ~2–3 µm-thick transmission electron microscopy (TEM) lamellae were prepared using focused ion beam (FIB) thinning across the boundary between the last- and first-formed carbonates.

TEM investigations of the Berger-Károly and Sonnenberg samples showed evidence for (001) aragonite stacking faults (SFs) in the first-formed aragonite. This new type of SF is characterized by the disruption in the regular stacking sequence of (001) aragonite atomic planes on TEM images and streaking of reflections on diffraction patterns. Structure modelling and theory-based optimization suggested that the crystal structure of (001) aragonite SFs could be explained by the incorporation of (0001) calcite layers within aragonite. Abundant (0001) calcite twins occurred in the last grown calcite. Oxygen isotope data indicated that both the Berger-Károly and Sonnenberg samples formed under non-equilibrium conditions, whereas the Erzberg specimen formed near equilibrium, possibly explaining its well-crystalline aragonite.

We hypothesize that our findings can be generalized and that the occurrence of (001) SFs and (0001) calcite twins may provide new insights the long-studied formation process of metastable aragonite.

The project is supported by the NKFI 141894 grant.

MINERAL IMPURITIES ALONG THE GRAPHITE VALUE CHAIN

Gabriella Obbágy*, Róbert Arató, Zsolt Dallos & Frank Melcher
Montanuniversität Leoben, Chair of Geology and Economic Geology, Leoben, Austria
* E-mail: gabriella.obbagy-arato@unileoben.ac.at

Graphite is a critical raw material essential for energy storage technologies, most commonly used as anode material in lithium-ion batteries. The EU's Critical Raw Materials Act targets more diversified and responsible sourcing of each critical raw material by limiting imports from any single non-EU supplier to 65% by 2030. However, currently no standardized method exists to trace or distinguish between natural graphite sources.

Graphite ore is extracted from heterogeneous geological environments. The ore is crushed and floated on-site, resulting in the globally traded concentrates of ca. 95% purity. Our goal is to develop a fingerprinting method for major natural graphite deposits by identifying material characteristics that remain traceable along (at least part of) the value chain. In-situ analytical methods (e.g. LA-ICP-MS and LIBS) show a wide range of detectable elements at spatially restricted areas, indicating separate phases as the source of chemical differences between samples (Arató et al., 2025). However, until now it remained unclear what kind of phases are those and if they remain traceable along the value chain.

In this study, a sedimentary provenance analysis approach was applied to determine the source region of graphite concentrates. Phases with a density higher than graphite were separated in heavy liquid (δ=2.46 g/cm^3) to amplify the characteristic mineralogical signal of each locality. The separated mineral impurities were embedded into epoxy to facilitate further measurements. For morphological and chemical characterization and phase determination, an SEM-EDS-based particle analysis system (Carl Zeiss SmartPI™) was used. Each detected phase type was cross-checked via Raman spectroscopy and a database was established for automatic phase identification. The most common mineral impurities in the graphite concentrates are quartz, mica, plagioclase and iron oxides, but at some localities amphiboles, pyroxenes, talc, apatite, titanite and sulfides are also frequent. The detected major phases are in excellent agreement with X-ray diffraction results obtained on bulk graphite concentrates. Furthermore, high-resolution transmission electron microscopy analysis shed light on the size and nature of mineral impurities. The identified minerals are mostly adsorbed on the surface of graphite flakes, while sheet silicates are also commonly intergrown with graphite. The size of the minerals covers a wide range from a few tens of nm up to the mm range.

For battery-specific applications, graphite concentrates are purified using alkali-autoclave leaching and/or hydrofluoric acid treatment to achieve a minimum purity of 99.95%. Such purified samples were also subjected to the above-described density separation and analytical protocol. As a consequence of chemical purification, some mineral phases are completely removed and the relative mineral impurity ratio becomes lower. On the other hand, the more resistant mineral phases (e.g., titanite, zircon) are enriched in the "heavy" fraction enabling traceability along the value chain.

This study was funded by the European Union under grant agreement no. 101091502, project MaDiTraCe – Material and Digital Traceability for the Certification of Critical Raw Materials, coordinated by the French Geological Survey (BRGM).

References

Arató R., Quarles Jr. D., Obbágy G., Dallos Z., Arató M., Gopon P. & Melcher F. (2025): Journal of Analytical Atomic Spectrometry, 40, 2526–2537.

PRELIMINARY RESULTS OF HYDROGEN MEASUREMENTS IN THE SOUTH APUSENI MOUNTAINS (ROMANIA)

Alexandra Orbán[1]*, Călin Baciu[1], Réka Szalay[2], Alexandru Lupulescu[1], Boglárka-Mercedesz Kis[2,3], Lóránd Silye[2] & Gábor Tari[4]

[1] Babeș-Bolyai University, Faculty of Environmental Science and Engineering, Cluj-Napoca, Romania

[2] Babeș-Bolyai University, Faculty of Biology and Geology, Department of Geology, Cluj-Napoca, Romania

[3] MTA–ELTE Volcanology Research Group, Budapest, Hungary

[4] OMV Exploration & Production, GmbH, Vienna, Austria

* E-mail: alexandra.orban@ubbcluj.ro

The Mures Valley ophiolitic series in the southern Apuseni Mountains (SAM) represents a significant location for natural hydrogen research in Romania, given its extensive area and the depths of mafic and ultramafic rocks, which are favourable for hydrogen generation via water-rock interactions.

Soil gas samples were collected and measured in October 2024 and June 2025, using a 2x2 km grid across three designated zones within the study area. A steel probe was hammered into the soil to a depth of 70-80 cm prior to measuring the soil gas with a BIOGAS 5000 instrument connected to it. The probe was elevated at intervals of 10 cm for repeated gas sampling. The instrument simultaneously measures four gases: H2, CO2, O2, and CH4. CO2 and CH4 are detected using an infrared sensor, with measurements ranging from 0-100 vol%. Hydrogen and oxygen are measured by an electrochemical sensor, where oxygen is quantified in vol% (0-25 vol%) and hydrogen is measured in ppmv (0-1000 ppmv). The instrument also measures air pressure and balance gas, with a pump flow rate of 550 ml/min. A total of 239 soil gas measurements was conducted to date, comprising 233 spot measurements and the remaining being control measurements at locations where hydrogen levels reached 100 ppmv. The hydrogen concentration in the study area is typically around 10 ppmv, with occasional instances of reaching or exceeding 100 ppmv. CO2 levels peaked at 11 vol%, while O2 concentrations were relatively high. Methane concentrations tended to stay below the detection limit of the sensor. The anomalously high hydrogen values were re-measured resulting in a large scatter in concentration values, indicating that the spatial and temporal variability of hydrogen in soil gas is considerable. This phenomenon can be attributed to its status as the smallest element, translating to less effective retainment in soil compared to all other gases. Elevated CO2 levels are associated with increased hydrogen readings, whereas O2 exhibits a negative correlation with CO2. Additional research is required to improve the understanding of the origin of hydrogen, derived from natural deep source and/or caused by biological processes at shallow depth. These alternative or complementary sources will be identified primarily through C and H isotope measurements.

PETROLOGY OF THE ANDESITIC ROCKS FROM THE SLANSKÉ VRCHY MOUNTAINS

Jörg Ostendorf[1], Milan Kohút[2]* & Robert Anczkiewicz[1]
[1] Polish Academy of Sciences, Institute of Geological Science, Kraków, Poland
[2] Slovak Academy of Sciences, Earth Science Institute, Bratislava, Slovakia
* E-mail: milan.kohut@savba.sk

The Slanské vrchy Mts. (SVM) geologically belong to the East Slovakian Neovolcanic Field, and their genesis is associated with the development of the Transcarpathian Basin. They form an approximately 50 km long, N–S trending, 12–20 km wide volcanic mountain range, stretching from the town of Prešov to the Hungarian border. The following volcanic formations (centres) have been defined from north to south: Šebastovka, Šťavica, Zlatá Baňa, Ošvárska, Makovica, Vechec, Rankovské skaly, Strechový vrch, Bogota, Hradisko, Bradlo, Milič and Čierný vrch (Kaličiak & Žec, 1995). In the published geological map, several forms of volcanic rocks were identified, such as lava flows, intrusions, necks, dikes, shallow laccoliths, extrusive domes, and autochthonous pyroclastics. Locally, columnar jointing structure was observed in lava flows. Petrographically and geochemically, the studied rocks of the SVM are classified as andesites and dacites as well as one basaltic andesite forming a magmatic enclave in andesite. The SiO_2 values in the studied rocks vary from 54.47 to 64.86 wt.% and are negatively correlated with MgO, ranging from 4.78 to 1.05 wt.%. The CaO (8.2–4.4 wt.%) and Fe_2O_3 (7.9–4.8 wt.%) contents decrease with increasing SiO_2, while the K_2O values (0.9–2.8 wt.%) are positively correlated with SiO_2. Chondrite-normalized (C1) REE diagrams of the SVM volcanic rocks indicate LREE enrichment. Andesite whole-rock $^{87}Sr/^{86}Sr_{(12Ma)}$ ratios (0.7071 to 0.7096) are negatively correlated with $\varepsilon Nd_{(12Ma)}$ (–1.0 to –7.0). The $\varepsilon Hf_{(12Ma)}$ values of andesites range from +2.8 to –4.6 and are positively correlated with $\varepsilon Nd_{(12Ma)}$. Dacites from the SVM show essentially similar trends in the Sr, Nd, and Hf isotopic compositions ($^{87}Sr/^{86}Sr_{(12Ma)}$ = 0.7078 to 0.7104; $\varepsilon Nd_{(12Ma)}$ = –2.8 to –6.9; $\varepsilon Hf_{(12Ma)}$ = +0.22 to –6.2), indicating that dacites are not simply products of more advanced crustal differentiation. In general, the isotope systematics reflect contributions of both mantle and crustal components to the magmatic system.

U–Pb LA-ICP-MS dating of 10 zircon separates from andesites and dacites of the SVM reveals a practically uniform age of about 12 Ma (Ostendorf et al., 2025). The similar zircon ages as well as the well-correlated isotopic compositions of andesites and dacites indicate a genetic relationship of all volcanic centres in the SVM chain. Therefore, we presume contributions of similar sources to the volcanic system and initial magma formation under similar physicochemical conditions. Differentiation probably occurred in a complex trans-crustal zone, involving processes of mixing, assimilation, storage, and homogenization (MASH) in the lower crust. This assumption is supported by clino- and orthopyroxene geochemistry, which indicates a complex crystal cargo in the SVM volcanics related to crystallization at different crustal levels. The pyroxenes are in disequilibrium with their host rocks (grew during earlier stage(s), probably deep in the crust). Considering an overall lack of zircon inheritance, the main location of assimilation was most likely located in a deeper crustal MASH zone. Furthermore, large zircon crystals that appear predominantly homogeneous or show broad-banded zoning in the CL images, indicate reworking of advanced fractionation products. Plagioclase crystals with sieved cores or cores containing rounded pyroxene and Fe-Ti oxide inclusions overgrown by another plagioclase generation indicate changing physicochemical conditions of the magmatic system. However, contamination at higher crustal levels cannot be fully excluded, and could be one of the reasons for some of the scatter in elemental and isotopic plots.

The timing of volcanism indicates magma generation in an extensional tectonic regime. Most likely, initial magma generation in the mantle was triggered by mantle upwelling. This could be either related to extension and decompression melting of passively upwelling mantle, or alternatively, melt generation in the upper mantle could be related to gravitational removal of the lower part of thickened Miocene lithosphere.

References

Kaličiak M. & Žec B. (1995): Acta Vulcanologica, 7, 87–95.
Ostendorf J., Anczkiewicz R. & Kohút M. (2025): Lithos, 496, 107929

A REVIEW OF ISOTOPE RATIO ANALYSES BY MC-ICPMS IN ATOMKI

László Palcsu*
HUN-REN Institute for Nuclear Research, Debrecen
* E-mail: palcsu.laszlo@atomki.hu

Since the installation of a Neptune Plus multi-collector inductively coupled plasma ion source mass spectrometer (MC-ICPMS), numerous methods have been adapted for accurate isotope analyses of different elements to study geochemical, biological and hydrological processes.

As a first method, the uranium-thorium dating technique has been worked out. Besides the chemical separation of uranium and thorium, the main challenge was to prepare and accurately determine the isotope composition of a ^{233}U-^{236}U-^{229}Th triple spike. While the uncertainty of the gravimetric analysis for the isotope ratios was about 0.5%, the normalization with a calcite sample of infinite age could reduce the error below 0.5‰. The U-Th dating is now frequently used to date carbonate samples (Temovski et al, 2024; Újvári et al., 2024). Soon after the installation of Neptune Plus, the analysis of ^{87}Sr/^{86}Sr ratio has been developed for archaeological, geological and hydrological studies (Cavazzuti et al., 2021; Haas et al., 2022). For provenance analysis, lead isotopes were analysed from ceramic glaze from the Middle Ages (Horváth et al., 2022). The potential of high resolution measurement has been demonstrated in case of iron isotope ratios of ferromanganese nodules (Sipos et al., 2023). Extreme precision could be achieved for δ^{238}U of limestone sequences (Somlyay et al., 2023).

The Neptune Plus MC-ICPMS together with the installation of other state-of-the-art methods like clumped isotope thermometry (Temovski et al., 2022) makes the basis of a well-equipped isotope laboratory in Central Europe.

The presentation will exemplify the main achievements as well as show challenging case studies.

References

Cavazzuti C., Hajdu T., Lugli F., Sperduti A., Vicze M, Horváth A, Major I., Molnár M., Palcsu L. & Kiss V. (2021): PLoS ONE 16(7), e0254360

Haas J., Budai T., Hips K., Czuppon, G., Győri O., Horváth A. & Héja G. (2022): International Journal of Earth Sciences, 111, 245–268.

Horváth A., Bajnóczi B., Györkös D. & Palcsu L. (2022): Archaeometry, 65, 1004–1017.

Sipos P., Kovács I., Barna G., Tóth A., Makó A., Palcsu L., Kiss G.I., Horváth A. & Puskás-Preszner A. (2023): Geoderma, 430, 116286

Somlyay A., Palcsu L., Kiss G.I., Clarkson M.O., Kovács E.B., Vallner Z., Zajzon N. & Pálfy J. (2023): Earth and Planetary Science Letters, 614, 118190

Temovski M., Rinyu L., Futó I., Molnár K., Túri M., Demény A., Otoničar B., Dublyansky Y., Audra P., Polyak V., Asmerom Y. & Palcsu L. (2022) Scientific Reports, 12, 9202

Temovski M., Wieser A., Marchhart O., Braun M., Madarász B., Kiss G.I., Palcsu L. & Ruszkiczay-Rüdiger Z. (2024): Geomorphology, 445, 108994

Újvári G., Schneider R., Stevens T., Rinyu L., Kiss G.I., Buylaert J.P., Murray A.S., Challier A.J.M., Kurbanov R., Khormali F., Benedek J., Temovski M., Vargas D. & Palcsu L. (2024): Geochimica et Cosmochimica Acta, 386, 110–126.

Geochemical composition of olivine phenocrysts from the alkaline basalts of the Perşani Volcanic Field with a focus on noble gas isotope content - Insights into the characteristics of the magma source region

Emese Pánczél[1,2]*, Szabolcs Harangi[1,2], Kata Molnár[2,3], György Czuppon[2] & Réka Lukács[1,2]

[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary

[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[3] HUN-REN Institute for Nuclear Research, Geochronology Group, Debrecen, Hungary

* E-mail: emipanczel7@gmail.com

The noble gas isotope ratios, especially the $^{3}He/^{4}He$, are reliable indicators of the geochemical characteristics of the source region of basaltic magmas in the asthenospheric mantle, also indicating the possible magma contamination with crustal and atmospheric fluids. To gain insights into the magma origin, noble gas isotopes can be detected from natural volcanic degassing, from unaltered volcanic glass, or fluid inclusions within primary mineral phases (e.g., olivine, pyroxene) of basaltic rocks.

In this study, we measured the noble gas isotope content of fluid inclusions within olivine phenocrysts from the alkaline basalts of the Quaternary Perşani Volcanic Field (PVF) in Romania. The PVF is located near the Vrancea seismic zone, where frequent earthquakes with deep hypocentres suggest a near-vertical descending lithospheric slab into the upper mantle. Alkaline basaltic magmas of the PVF were generated by decompressional low-degree partial melting in the upwelling asthenosphere and ascended rapidly.

Thus, the noble gas isotope composition of the primary fluid inclusions in olivine pheno-/autocrysts reflects the characteristics of the asthenospheric mantle. In the Carpathian–Pannonian Region, we firstly detected noble gas isotopes from phenocrysts of basaltic rocks. We sampled threedifferent alkaline basalt eruption products of the PVF from different eruption episodes (Racoş, Gruiu, Bogata). After a multi-step sample preparation, we analyzed the olivine separates using a noble gas mass spectrometer (HUN-REN Institute for Nuclear Research, Debrecen, Hungary). Petrographic characteristics of the PVF samples and the major element composition of most olivine phenocrysts suggest crystallization from primary basaltic magma. Due to rapid magma ascent, the olivine crystals preserved the original noble gas isotope ratios in their primary fluid inclusions.

Noble gas isotopes were succesfully detected from all olivin separates. We got relatively low R/Ra values (the $^{3}He/^{4}He$ of the sample normalized to the atmospheric $^{3}He/^{4}He$ ratio), which are lower than the R/Ra values obtained from the olivine and pyroxene crystals of lithospheric mantle xenoliths in the PVF alkaline basalts, thus suggesting geochemical differences between the local asthenospheric and lithospheric mantle. Our results are also lower than the typical helium isotopic ratio of the depleted mantle (MORB source). The low R/Ra values can be explained by metasomatism of the asthenospheric magma source region with crustal fluids during former subduction and/or ^{4}He addition to the asthenosphere from the radioactive decay of U and Th originated from the subducted lithospheric slab. Another possible explanation could be the lithologic heterogeneity of the magma source region.

The detailed olivine geochemistry and noble gas isotope data obtained in this study, and compared with literature data, can help improve our understanding of the local mantle characteristics and geodynamic conditions beneath the PVF.

PETROGENESIS AND AMPHIBOLE–MELT TRACE ELEMENT PARTITIONING OF THE 156 KA HARAMUL MIC CRYSTAL-RICH DACITE, CIOMADUL, ROMANIA

Emese Pánczél[1,2]*, Szabolcs Harangi[1,2]*, Maurizio Petrelli[3], Răzvan–Gabriel Popa[4], Attila Virág[1,2], Ioan Seghedi[5], Olivier Bachmann[4], Réka Lukács[1,2]

[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary

[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary

[3] Department of Physics and Geology, University of Perugia, Piazza Università, 06100, Perugia, Italy

[4] Department of Earth Sciences, Institute of Geochemistry and Petrology, ETH Zürich, Zürich, Switzerland

[5] Romanian Academy, Institute of Geodynamics Sabba S. Ştefanescu, Bucharest, Romania

* E-mail: emipanczel7@gmail.com; harangi.szabolcs@ttk.elte.hu

The 156 ka, crystal-rich (~40 vol%) Haramul Mic dacite represents eruption of a crystal mush. It marks the first eruptive product of the Ciomadul Volcanic Complex, east-central Europe, following at least 100 kyr of dormancy. The mineral phases (plagioclase, amphibole, biotite, apatite, titanite and zircon) and the interstitial glass have relatively restricted major and trace element composition. Thermobarometric and hygrometric calculations indicate a low-temperature (~720 °C), low-pressure (~300 MPa), water-saturated (dissolved $H2O$~6.5 wt%) and oxidizing silicic magmatic system. A comprehensive set of amphibole-melt trace element partition coefficient data is provided, applicable to low-temperature, near-eutectic silicic volcanic and plutonic systems. The maximum partition coefficient (D_0=8.7±0.1) and the optimal ionic radius (r_0=1.0494±0.0008 Å) for trivalent elements, as determined from Onuma plots, are consistent with an evolved silicic magmatic system and a low-magnesian amphibole composition. Additionally, mineral-melt trace element partition coefficients are calculated for coexistent titanite, zircon, plagioclase and biotite. We note that in highly evolved silicic volcanic systems, partition coefficients remain consistently similar, even with slight variations in magma composition and conditions near the thermal minimum. In contrast to the subsequent eruptions, there is no evidence for mafic magma recharge and mixing as eruption initiation for the Haramul Mic. Instead, effective thermomechanical reactivation of a portion of the long-standing crystal mush, followed by rapid magma ascent is envisaged. Ciomadul provides an example where multiple processes can contribute to eruption initiation, as reflected in the textural and compositional characteristics of the crystal cargo, despite the relatively uniform composition of the erupted magma.

UNRAVELING TRACE ELEMENTAL COMPOSITIONAL VARIATION BY LA-ICP-MS MAPPING

Maria Pârlea[1,2]*, Vlad-Victor Ene[1,3], Peter Luffi[1,3,4] & Mihai Ducea[1]
[1] University of Bucharest, Department of Geology, Bucharest, Romania
[2] Doctoral school of Geology, University of Geology, Bucharest, Romania
[3] Romanian Academy, Institute of Geodynamics Sabba S. Ştefanescu, Bucharest, Romania
[4] Geological Institute of Romania, Bucharest Romania
* E-mail: mariaparlea@yahoo.com

Understanding the spatial distribution of trace elements in minerals is essential for reconstructing the geological history of rocks. Relying only on major elements or bulk-rock trace element analyses often overlooks valuable information that is preserved at the scale of individual crystals. That is because many trace elements exhibit lower diffusion coefficients compared to major elements, making them more resistant to high-temperature re-equilibration and thus more reliable recorders of primary zoning and crystallization conditions (Jackson et al., 1992).

In this study, we optimized LA-ICP-MS mapping to visualize and quantify trace element zoning in igneous minerals, like garnets, amphiboles and zircons.

Trace element compositional maps can be generated using a variety of analytical setups. In this study, the mapping was carried out at the GeoChron Laboratory, University of Bucharest, using a Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) system. The instrumentation includes a Teledyne Iridia 193 nm excimer Ar–F laser, equipped with a Cobalt ablation cell using helium as carrier gas (0.6 L/min). This is coupled to a Thermo Scientific iCAP RQ quadrupole mass spectrometer, utilizing the Aerosol Rapid Introduction System (ARIS) which is ideal for high-resolution mapping.

Maps were acquired using a circular laser beam spot ranging from 3 to 12 µm, scanning in a series of parallel rasters within user-defined polygonal areas around the target minerals. Analytical parameters included a repetition rate of 300 Hz, energy density of 4 J/cm^2, and laser dosages between 4 and 12, with no overlap between lines. Due to the required fast washout, acquisition cycles are limited to four isotopes per run, but this is offset by the resulting shallow ablation depth—estimated to be less than 1 µm (Ubide et al., 2015), which allows repeated ablation of the same crystal.

In this study, different elements were measured in various minerals, with a particular focus on ^{43}Ca, ^{89}Y, ^{147}Sm, ^{153}Eu, ^{157}Gd, ^{163}Dy, ^{172}Yb, ^{206}Pb, ^{207}Pb, and ^{238}U. Dwell times ranged from 0.001 to 0.0076 seconds, resulting in a total sweep time of 0.0223 seconds per run. For quality control and calibration, NIST612 and NIST610 glass standards were used in a bracketing scheme, with three lines measured at both the beginning and end of each run.

Raw data were processed using Iolite v4 (Paton et al., 2011). Laser log files were synchronized with the ICP-MS signal to ensure spatial accuracy. Background correction was performed using the reference material, and data reduction was carried out through the 'Trace Elements' Data Reduction Scheme (DRS), which applies externally calibrated standard values and internal standardization for quantification. Following reduction, elemental distribution maps were generated using the CellSpace module, which averages signal intensity across overlapping ablation spots, depending on the degree of spatial overlap. The spatial resolution achieved in this study exceeds that reported in comparable works (e.g., Ubide et al., 2015), owing to the use of a high repetition rate (300 Hz) and small laser spot sizes (3–9 µm).

Compared to traditional spot analysis, LA-ICP-MS mapping offers spatial coverage along with detection limits—down to the ppm level—surpassing techniques such as SEM-EDS and providing a more cost-effective alternative to SIMS. The high-resolution 2D maps obtained through this method reveal geochemical patterns and zoning features that are often invisible using single spot techniques. By preserving the spatial context of elemental distributions, this approach enables more nuanced interpretations of mineral growth histories and petrogenetic processes. As such, trace element mapping via LA-ICP-MS represents a powerful tool for modern petrology and is bound to play a central role in future geochemical and petrological research.

References

Jackson S.E., Longerich H.P., Dunning G.R. & Fryer B.J. (1992): Canadian Mineralogist, 30, 1049–1064.

Paton C., Hellstrom J., Paul B., Woodhead J. & Hergt J. (2011): Journal of Analytical Atomic Spectrometry, 26, 2508–2518.

Ubide T., McKenna C.A., Chew D.M. & Kamber B.S. (2015): Chemical Geology, 409, 157–168.

GEOLOGICAL SETTING, PETROGRAPHY, AND GEOCHRONOLOGY OF THE MIOCENE VITRO-CRYSTAL TUFF FROM KECEROVSKÉ PEKLAŇY, EAST SLOVAK BASIN (TRANSCARPATHIAN BASIN)

Samuel Rybár[1,2], Katarína Šarinová[3], Fred Jourdan[4,5], Celia Mayers[5], Marcel Guillon[6], Réka Lukács[7,8]
[1] Comenius University, Department of Geology and Paleontology, Bratislava, Slovakia
[2] Technical University of Ostrava, Department of Geodesy and Mine Surveying, Ostrava Poruba, Czech Republic
[3] Comenius University, Department of Mineralogy, Petrology and Economic Geology, Bratislava, Slovakia
[4] Curtin University, SSTC and TIGeR, School of Earth and Planetary Sciences, Perth, Australia
[5] Curtin University, Western Australian Argon Isotope Facility and John de Laeter Centre, Perth, Australia
[6] ETH Zurich, Institute of Geochemistry and Petrology, Zurich, Switzerland
[7] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[8] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
* E-mail: samuelrybar3@gmail.com

1. Introduction

The Transcarpathian Basin represents the northeastern segment of the Pannonian Basin System, extending across eastern Slovakia, western Ukraine, northern Romania, and partially into northeastern Hungary (Horváth, 1995). Within this extensive basin system, the Slovak portion – commonly referred to as the East Slovak Basin (ESB) (Fig. 1) or Slovak part of the Transcarpathian Basin (STB) – forms a major Neogene depocenter. The STB is structurally segmented by the Slanské vrchy Mountains into two main sub-basins: the Trebišov sub-basin, where sediment thickness reaches 6–7 km (Řeřicha & Rudinec, 1979; Fusán et al., 1987), and the Prešov sub-basin, with over 3 km of sediment accumulation (Fusán et al., 1987). A prominent pyroclastic unit within the southern part of the Prešov sub-basin (Košice depocenter) is the vitro-crystal Rankovce Tuff (Vass, 2002), which crops out and was drilled (KP-1 well) near the village of Kecerovské Pekľaňy (Fig. 1), at the foothills of the Slanské vrchy Mts. This tuff unit has

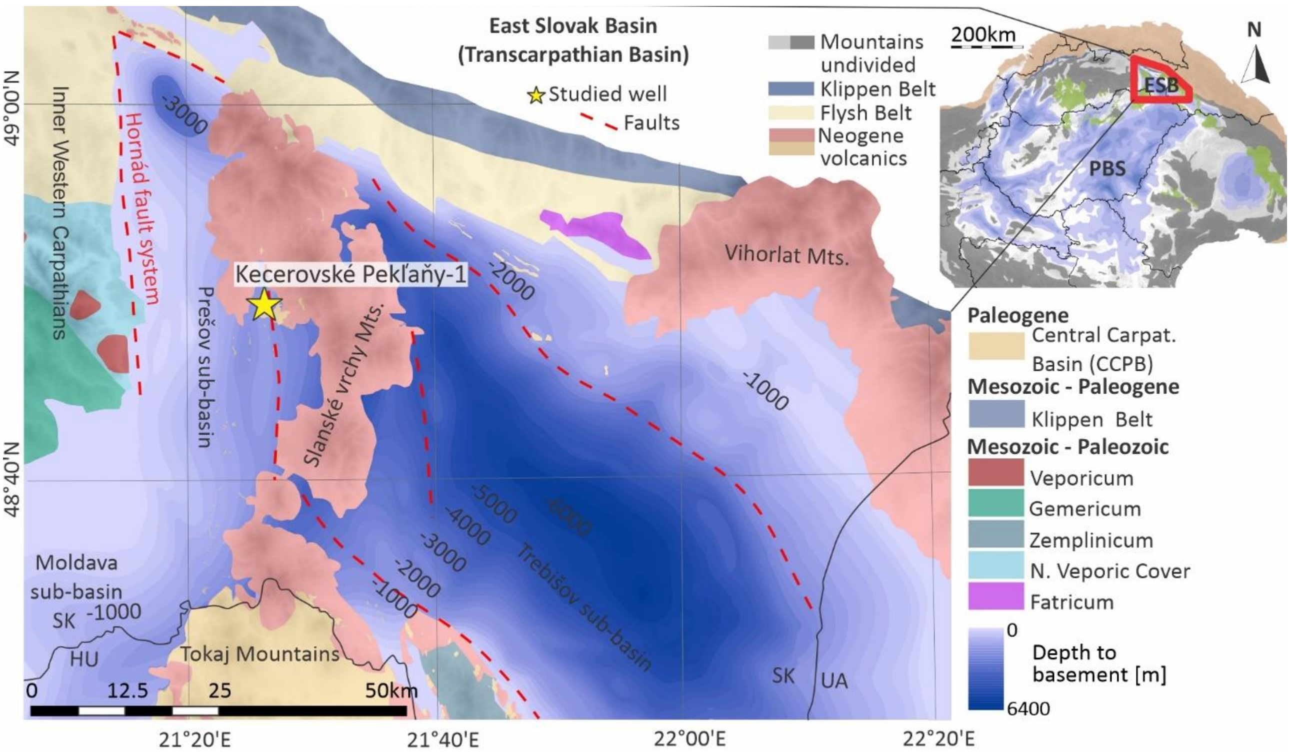


Figure 1. *Location of the East Slovak Basin - ESB (Slovak part of the Transcarpathian Basin - STB) within the Pannonian Basin System - PBS. Abbreviations: SK = Slovakia; UA = Ukraine; HU = Hungary.*

regional significance due to its lateral continuity and stratigraphic position. It may serve as a key marker horizon and a potential boundary between the upper Badenian and Sarmatian stages (intra-Serravallian), provided its geochronological age is accurately constrained. Until now, its age has been inferred only through biostratigraphy, placing it tentatively within the Sarmatian (upper Serravallian). The present study aims to refine the characterization of the Kecerovské Pekľaňy Tuff (Rankovce Tuff) through an integrated analysis of its geological setting, petrography, and geochronology, contributing to both regional stratigraphy and the understanding of Miocene volcanism in the STB.

2. Geological setting

During the Miocene, the East Slovak Basin experienced a complex tectonic evolution. Initially, it developed as a compressional foredeep, likely active until the Ottnangian (lower Burdigalian). Following the disintegration of this older basin – possibly genetically linked to the Central Carpathian Paleogene Basin (Subová et al., 2024a,b) as defined by Gross (1984) – the basin then transitioned into a transtensional setting. This phase was subsequently overprinted by orthogonal rifting, all occurring within the broader geodynamic context of the Pannonian back-arc basin. The transtensional to extensional regime is interpreted to have developed from the Karpatian through to the lower Pannonian (Burdigalian/Langhian to early Tortonian; Subová et al., 2024a,b). Volcanic activity accompanied this entire tectonic interval and is evidenced by both exposed volcanic centers (e.g., the Slanské vrchy and Vihorlat Mountains; Fig. 1) and buried volcanic fields (e.g., the Malčice and Čičarovce fields) (Harangi & Lenkey, 2007; Lexa et al., 2010; Lukács et al., 2024). These centers produced widespread bimodal rhyolitic and andesitic tuff horizons, many of which have significant potential as regional marker beds. Within this tectono-volcanic framework, the vitro-crystal tuff at Kecerovské Pekľaňy (Fig. 2) – likely a part of the Rankovce Tuff horizon (Vass, 2002) – is of particular stratigraphic and geological importance. Stratigraphically assigned to the Sarmatian (upper Serravallian), this pyroclastic formation preserved in both proximal and more distal depositional environments represents a distinctive volcanic episode.

3. Petrography

The Kecerovské Pekľaňy vitro-crystal tuff (sampled from the Kecerovské Pekľany-1 well, lat. 48°49'14.35"N, lon. 21°26'15.27"E, Core 1, Box 4 at a depth of 603 - 604 m) exhibits a characteristic mineral assemblage dominated by feldspars and volcanic glass (Fig. 3). The primary constituents include sanidine (Or_{70}), plagioclase (An_{30}), and quartz, accompanied by subordinate biotite (annite), which is frequently slightly altered. Accessory phases include zircon, apatite, rutile, monazite, and finely disseminated sulphide minerals, primarily Pb-Zn types. Volcanic glass shards are abundant and often appear interstitial to the crystalline phases, confirming a pyroclastic origin. Large sanidine crystals are notably zoned, exhibiting an increase in barium (Ba) content

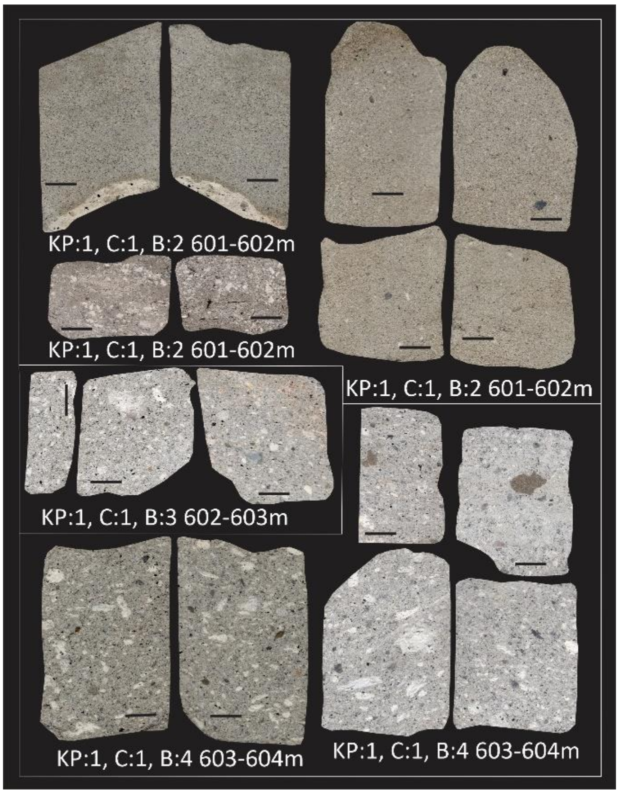


Figure 2. *Scan images of vitro crystal tuff from the Kecerovské Pekľany-1 well, core 1, boxes 2–4, depth interval 601–604 m.* ***Box B:2 (601–602 m) – Tuffite.*** *Appearance: Generally greyish, fine-grained, massive texture. Clast content: Sparse, small lithic and crystal fragments scattered within a dominant fine-ash matrix. Matrix: Predominantly altered volcanic ash with some detrital material, giving it a hybrid (volcaniclastic–sedimentary) character. Interpretation: Rock corresponds to tuffite – volcaniclastic material mixed with significant proportion of sedimentary particles, relatively poor in visible glass shards but ocasionaly includes large pumice fragments.* ***Box B:3 (602–603 m) – Tuff (transition to tuffite).*** *Appearance: Light grey to mottled texture with noticeable darker lithic fragments. Clast content: Abundant crystal and lithic fragments (plagioclase, quartz, volcanic lithics) are embedded in finer matrix. Some elongated pumice shards appear to be preserved. Matrix: Ash-sized material dominates, less massive than B:2, suggesting more direct pyroclastic input. Interpretation: Likely fine-grained tuff, possibly transitional toward tuffite, due to sediment admixture but with clear pyroclastic shard content.* ***Box B:4 (603–604 m) – Vitro crystal tuff.*** *Appearance: Light grey with conspicuous white elongated pumice fragments and darker lithic clasts. Clast content: High proportion of crystal fragments (feldspar, quartz) and lithics, set in an ash matrix. Pumice clasts show elongation and flattening, indicating compaction. Texture: More heterogeneous compared to B:2 and B:3.*

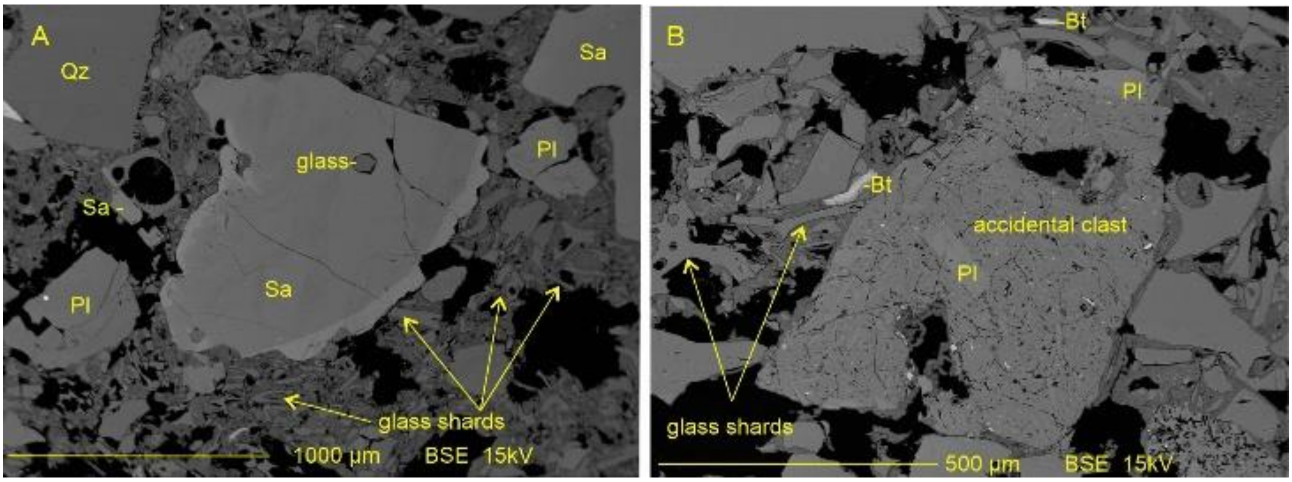


Figure 3. *BSE images of the vitro crystal fuff from Kecerovcké Pekľany-1 well core:1 box:4 603-604 m. Panel A - Qz (Quartz): Large angular crystal fragment. Pl (Plagioclase): Several subhedral to anhedral plagioclase grains are visible. Sa (Sanidine). Gl (Glass): Volcanic glass matrix surrounding the mineral grains. Glass shards: Elongated, cuspate shapes characteristic of volcanic ash/tuff. Their vesicular and splintery morphologies indicate quenching of volcanic melt. Panel B - Pl (Plagioclase) in accidental clast: Subhedral to anhedral grains, some showing zoning or alteration. Bt (Biotite): Flaky/tabular grain. Accidental clast: Large lithic fragment with a distinct internal texture different from the juvenile volcanic material. Glass shards: Again present, cuspate vesicular particles forming the matrix.*

towards their rims – a feature suggestive of magmatic differentiation during crystallization. Accidental lithic fragments of andesitic composition are common within the matrix, representing incorporation of older volcanic basement or conduit wall material during explosive eruption phases. Slight alteration of biotite may indicate post-depositional hydrothermal or diagenetic processes, yet the primary magmatic features remain well preserved. Collectively, the mineralogy and textures confirm a rhyolitic pyroclastic origin and highlight the tuff as a potential marker horizon within the Middle Miocene volcanic stratigraphy of the ESB.

4. Geochronology

$^{40}Ar/^{39}Ar$ geochronological analysis of sanidine crystals from the Kecerovské Pekľaňy vitro-crystal tuff done at Western Australian Argon Isotope Facility and John de Laeter Centre, Curtin University, reveals the presence of two distinct age populations, indicating the existence of at least two generations of sanidine. The older population yields an age range between 13.11 and 13.33 Ma, while the younger group defines a coherent isochron with an age of 12.27 ± 0.43 Ma. The dating was conducted using the single-crystal laser fusion $^{40}Ar/^{39}Ar$ dating. Sanidine crystals were separated from the tuff, irradiated in a nuclear reactor to produce ^{39}Ar, and individually fused using a laser. Argon isotopic ratios were measured with a mass spectrometer, and crystallization ages were determined for each grain. The distribution of single-grain ages was used to identify distinct crystal populations, reflecting different thermal or eruptive histories. The presence of two sanidine age populations suggests a complex evolution. The older crystals likely represent crystals that formed earlier within a context of an older eruption event (possibly associated with the older upper Badenian Kráľovce Tuff) and were subsequently entrained in the new eruptive phase likely associated with the Rankovce Tuff. The younger sanidine generation thus probably crystallized shortly before or during the eruption event that produced the dated tuff. Zircon U-Pb dating were performed on separated zircon crystals by LA-ICP-MS at the ETH Zürich. Concordant zircon dates vary between 13.62 and 12.12 Ma and have two xenocrystic ages of 473 and 312 Ma. The uncertainty of the individual dates is ~3%. The youngest age population yields an age of 12.56 ± 0.20 Ma. When deconvoluting the data spectrum by the finite mixture algorithm of IsoplotR (after Galbraith, 1990) three peaks can be identified at 13.37 ± 0.21 Ma (17%), 12.78 ± 0.15 Ma (55%) and 12.35 ± 0.17 Ma (28%).

5. Discussion

The combined petrographic and geochronological data from the Kecerovské Pekľaňy vitro-crystal tuff provide valuable insights into the volcanic evolution of the East Slovak Basin during the Middle Miocene. The observed mineral assemblage – dominated by sanidine, plagioclase, quartz, volcanic glass, and accessory phases such as zircon, rutile, and sulphides – along with rhyolitic glass shards, confirms a high-temperature pyroclastic origin for the unit. Zoned sanidine with increasing Ba toward the rims suggests crystallization within a chemically evolving magmatic system, indicative of progressive differentiation or recharge of a rhyolitic magma chamber. The presence of accidental andesitic lithoclasts within the tuff matrix supports a scenario of bimodal volcanism, which is consistent with regional trends in the East Slovak Basin and surrounding volcanic fields (Harangi & Lenkey, 2007; Lexa et al., 2010; Lukács et al., 2024). The Slanské vrchy and Vihorlat Mountains, along with buried volcanic centers like Malčice and Čičarovce, document the persistence of both rhyolitic and andesitic volcanism throughout the Badenian to early Pannonian (Langhian to early Tortonian) interval. This bimodal volcanic activity reflects a tectonic setting influenced by transtension and later back-arc rifting, likely driven by slab rollback and associated extension in the Pannonian Basin system (Horváth et al., 2006, 2015; Subová et al., 2024a,b). The $^{40}Ar/^{39}Ar$ dating results further support a complex geologic history. The older sanidine population (13.33–13.11 Ma) may represent an earlier eruptive event, potentially linked to the Kráľovce Tuff, which is stratigraphically placed within the upper Badenian (Vass, 2002). These crystals could have been remobilized and incorporated into the younger eruptive phase associated with the Rankovce Tuff (Vass, 2002). In contrast, the younger sanidine generation (12.27 ± 0.43 Ma) likely crystallized in situ during the final stages of magma evolution immediately preceding eruption. This is in agreement with the zircon U-Pb dates, where the youngest zircon population ages (12.56 or 12.35Ma) close the youngest sanidine age. Incorporation of zircons from older eruptions is also consistent with 72% zircon spots having dates between 13.37±0.21 Ma (17%) and 12.78±0.15 Ma (55%). These clear dual-age population of the Ar-Ar results and the range of zircon crystallization dates underscores the longevity and episodic nature of magmatic activity in the region. Overall, the Kecerovské Pekľaňy Tuff (Rankovce Tuff) serves as both a stratigraphic marker and a window into the dynamic volcanic and tectonic evolution of the ESB. Its detailed study contributes to refining the timing of volcanic episodes in the region and enhances our understanding of Middle Miocene back-arc volcanism within the broader Pannonian Basin framework.

6. Conclusions

This study provides a characterization of the Kecerovské Peklaňy vitro-crystal tuff, a pyroclastic unit of significant stratigraphic and volcanic relevance within the East Slovak Basin. Through the integration of field observations, petrographic analysis, and high-precision Sanidine $^{40}Ar/^{39}Ar$ and Zircon U-Pb geochronology, several important conclusions can be drawn. **Petrography** confirms the rhyolitic pyroclastic nature of the tuff, characterized by sanidine, plagioclase, quartz, volcanic glass, and accessory minerals such as zircon, apatite, rutile, and Pb-Zn sulphides. **Geochronological data** reveal two distinct age populations of sanidine: an older group ranging from 13.33 to 13.11 Ma, and a younger generation dated to 12.27 ± 0.43 Ma also supported by Zircon U-Pb ages. These results suggest a complex history, with remobilization of earlier-formed crystals from previous eruptive events – possibly associated with the upper Badenian (lower Serravallian) Kráľovce Tuff – into a younger eruptive phase likely represented by the Rankovce Tuff. The tuff's **stratigraphic position**, petrography, and age place it firmly within the Sarmatian (upper Serravallian), providing key temporal constraints for correlating volcanic events across the region. Its widespread distribution and distinct characteristics make it a reliable marker horizon within the Miocene stratigraphy of the ESB. The data also support a prolonged phase of **bimodal volcanism**, coeval with transtensional to extensional tectonics and regional back-arc basin development. These processes are consistent with the broader geodynamic framework of the Pannonian Basin, driven by slab rollback and orogenic collapse during the Miocene. In summary, this contribution enhances the resolution of the Middle Miocene volcanic framework and provides a basis for future regional correlations.

Acknowledgements

This study was supported by the Slovak Research and Development Agency under the contract No. APVV-23-0227. The research was also funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V04-00127 and by the Hungarian National Research, Development and Innovation Office (No. 145905). This work is also supported by the MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group. We extend our gratitude to the management of Nafta a.s. for allowing sampling campaigns in their repository.

References

Fusán O., Biely A., Ibrmajer J., Plančár J. & Rozložník L. (1987): In: The basement of the Tertiary of the Inner West Carpathians. State Geological Institute of Dionýz Štúr, Bratislava, 1–123.

Galbraith R.F., 1990. The radial plot: graphical assessment of spread in ages. Nuclear Tracks and Radiation Measurements, 17(3), pp.207–214.

Gross P., Köhler E. & Samuel O. (1984): Geologické správy, 81, 103–117.

Harangi Sz. & Lenkey L. (2007): In: Foulger G.R. & Jurdy D.M. (eds.): Plates, Plumes and Planetary Processes. Geological Society of America Special Paper, 418.

Horváth F. (1995): Marine and Petroleum Geology, 12, 837–844.

Horváth F., Bada G., Szafián P., Tari G., Ádám A. & Cloetingh S. (2006): Geological Society, London, Memoirs, 32, 191–206.

Horváth F., Musitz B., Balázs A., Végh A., Uhrin A., Nádor A., Koroknai B., Pap N., Tóth T. & Wórum G. (2015): Geothermics, 53, 328–352.

Lexa J., Seghedi I., Németh K., Szakács A., Konečný V., Pécskay Z., Fülöp A. & Kovacs M. (2010): Central European Journal of Geosciences, 2, 207–270.

Lukács R., Guillong M., Szepesi J., Szymanowski D., Portnyagin M., Józsa S., Bachmann O., Petrelli M., Müller S., Schiller D., Fodor L., Chelle-Michou C. & Harangi Sz. (2024): Gondwana Research, 130, 53–77.

Řeřicha M. & Rudinec R. (1979): Albinov – Vyhľadávací prieskum na živice – východoslovenský neogén. Vykonávací projekt vrtu Albinov-7. Moravské naftové doly, Hodonín, Archive number: 43964.

Subová V., Rybár S., Hudáčková N., Jamrich M., Jourdan F., Mayers C. & Sliva Ľ. (2024a): Geologica Carpathica, 75, 4, 243–269.

Subová V., Rybár S., Sliva Ľ. & Šály B. (2024b): In: Tari G.C., Kitchka A., Krézsek C., Lučić D., Markič M., Radivojević D., Sachsenhofer R.F. & Šujan M. (eds.): The Miocene Extensional Pannonian Superbasin, Volume 2: Geoenergy Exploration. Geological Society, London, Special Publications, 555.

Vass D. (2002): Lithostratigraphy of Western Carpathians: Neogene and Buda Paleogene. State Geological Institute of Dionýz Štúr, Bratislava, 1–202.

MACROLITHIC FINDS MADE OF METABASITES FROM CSANÁDPALOTA–FÖLDVÁR, SE HUNGARY (PRELIMINARY ARCHAEOMETRIC RESULTS)

Tamás Sági[1]*, Máté Biró[2], Veronika Szilágyi[3], Anna Priskin[4], Vajk Szeverényi[5] & Bálint Péterdi[6]
[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[2] Eötvös Loránd University, Department of Mineralogy, Budapest, Hungary
[3] HUN-REN Centre for Energy Research, Budapest, Hungary
[4] Hungarian National Museum, National Archaeological Institute, Budapest, Hungary
[5] University of Miskolc, Department of Archaeology, Miskolc, Hungary
[6] Supervisory Authority for Regulatory Affairs, Budapest, Hungary
* E-mail: cseregle@gmail.com

A large Late Bronze Age fortified settlement system was identified recently in SE Hungary. The largest (ca. 460 hectares) fortified megasite of this system in Hungary is Csanádpalota–Földvár. In the most recent excavation period (2011–2013) of the megasite, more than 100 Late Bronze Age features came to light. Finds of the Pre-Gáva (Cruceni–Belegis II) Culture (middle phase of the Late Bronze Age, ca. 1350–1100 BC) include 238 mostly fragmented macrolithic artefacts. A set of archaeological (Priskin, 2022) and petrological (Péterdi et al., 2024, 2025) analyses have already been carried out on this macrolithic material. The artefacts are made of sandstone (42%), quartzite–quartz rich sandstone (15%), micaceous metamorphic rocks (16%), volcanic rocks (14%), granite (5%), limestone (4%) and other materials, e.g. daub (9%). So far, only the petrological and geochemical characteristics of the andesitic (Péterdi et al., 2024) and alkaline basaltic (Péterdi et al., 2025) raw materials have been described in detail.

In this poster, we are presenting the preliminary results of our detailed petrographical and mineral chemical investigations of the metabasite raw materials. We also provide a rough estimation of the provenance of these raw materials.

The project has received funding from the Hungarian National Fund (NKA, Grant Nos. 3234/230, 207134/306, and 207134/00383), National Research, Development and Innovation Office (OTKA-FK 135805, OTKA-K-131814, and ADVANCED Research Grant No. 150223), and the Wenner-Gren Foundation (Dissertation Fieldwork Grant No. 9472).

References

Péterdi B., Priskin A. & Sági T. (2024): Archeometriai Műhely, XXI/4, 359–380.

Péterdi B., Priskin A., Ntaflos T., Biró M. & Sági T. (2025): Journal of Archaeological Science: Reports, 63, 105074

Priskin A. (2022): Antaeus, 38, 251–272.

HRABOVEC TUFF MEMBER AS A STRATIGRAPHIC MARKER IN THE EAST SLOVAKIAN BASIN

Katarína Šarinová[1*], Samuel Rybár[2,3], Jana Brčeková[1], Dawid Szymanowski[4], Marcel Guillong[4] & Réka Lukács[5,6]
[1] Comenius University, Department of Mineralogy, Petrology and Economic Geology, Bratislava, Slovakia
[2] Comenius University, Department of Geology and Paleontology, Bratislava, Slovakia
[3] Technical University of Ostrava, Department of Geodesy and Mine Surveying, Ostrava, Czech Republic
[4] ETH Zurich, Institute of Geochemistry and Petrology, Zurich, Switzerland
[5] MTA–HUN-REN CSFK Lendület "Momentum" Pannonian Volcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[6] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
*E-mail: katarina.sarinova@uniba.sk

1. Introduction

The East Slovakian Basin (Fig. 1) is an autonomous sub-unit of the Transcarpathian Basin and forms part of the Pannonian Basin System. Its evolution is linked to the subduction of an oceanic slab between the North European Platform and the ALCAPA plate (Ustaszewski et al., 2008; Lukács et al., 2024). The basin fill predominantly consists of Miocene clastic sediments, volcanic rocks, and evaporites (Subová et al., 2022, 2024a, b). A characteristic feature of this stratigraphy is an Early Badenian (Langhian) marine volcano-sedimentary complex, known as the Nižný Hrabovec Formation (Vass, 2002). This formation includes several volcanic layers, the most prominent being a 100–140 m thick zeolitized tuff interval, originally referred to as the Hrabovec Tuff Member (Slávik, 1968; Vass, 2002). At the surface, the Hrabovec Tuff forms an outcrop belt approximately 7 km long in the northern part of the basin (Fig. 1). The tuff extends further to the southeast, where it occurs at greater depths while still maintaining significant thickness (Vass et al., 2000). It represents one of the most economically important natural zeolite deposits in the region. The zeolites formed through the diagenetic alteration of volcanic glass shards, exhibiting vertical zonation from clinoptilolite to analcime (Šamajová, 1997; Tschegg et al., 2019).

Although the Hrabovec Tuff represents a significant stratigraphic marker, no comprehensive study has yet compared its various occurrences to determine whether they are linked to a single volcanic event or multiple eruptions. The aim of this research is to investigate the spatial variability, depositional processes, eruptive source(s), and timing of the Hrabovec Tuff. In its initial phase, the study focuses on the northern part of the East Slovakian Basin, where the Hrabovec Tuff Member is exposed at the surface (Fig. 1).

2. Data and methods

Samples were collected from two commercial zeolite quarries — Kučín Quarry (lat. 48°51'57.93"N, lon. 21°45'5.84"E) and Nižný Hrabovec Quarry (lat. 48°51'31.81"N, lon. 21°46'4.51"E), located approximately 1 km apart — as well as from two deep wells located approximately 14 km to the south: Rakovec-2 (sampled at 2500 m; lat. 48°45'7.24"N, lon. 21°47'7.59"E) and Trhovište-26 (sampled at depths of 2200 m and 2295 m; lat. 48°44'0.15"N, lon. 21°48'45.59"E; see Fig. 1).

A multi-analytical approach was applied, incorporating optical microscopy, X-ray diffraction, electron microprobe analysis (EMPA), zircon U–Pb dating using both laser ablation ICP-MS and CA-ID-TIMS techniques, as well as zircon Hf-isotope and trace element analysis.

3. Results and interpretations

All studied tuffs display a highly homogeneous composition, being predominantly fine-grained with a vitric texture. In the quarries, occasional rhythmic lamination was observed. Additionally, at Kučín Quarry, plant impressions and charred wood fragments are preserved along bedding planes.

3.1. Composition and alteration

The samples exhibit a similar primary mineral composition, comprising plagioclase (andesine), biotite (annite), extremely rare quartz and sanidine (Or_{69}), along with accessory minerals such as zircon, apatite, rutile, and ilmenite (Fig. 2). Volcanic glass shards, which represent the dominant component, have been extensively replaced by zeolite minerals. The groundmass is composed of zeolitic phases and siliceous material, reflecting burial diagenetic conditions. In surface exposures, glass shards and groundmass have been replaced by a Ca–Na clinoptilolite and silica in the form of opal-C/CT. In contrast, samples from deep wells show replacement by analcime and crystalline quartz. Additionally, deep well samples contain other secondary minerals such as phyllosilicates (illite–celadonite), Fe-chlorite, carbonates, and sulphides. In more coarse-grained, probably

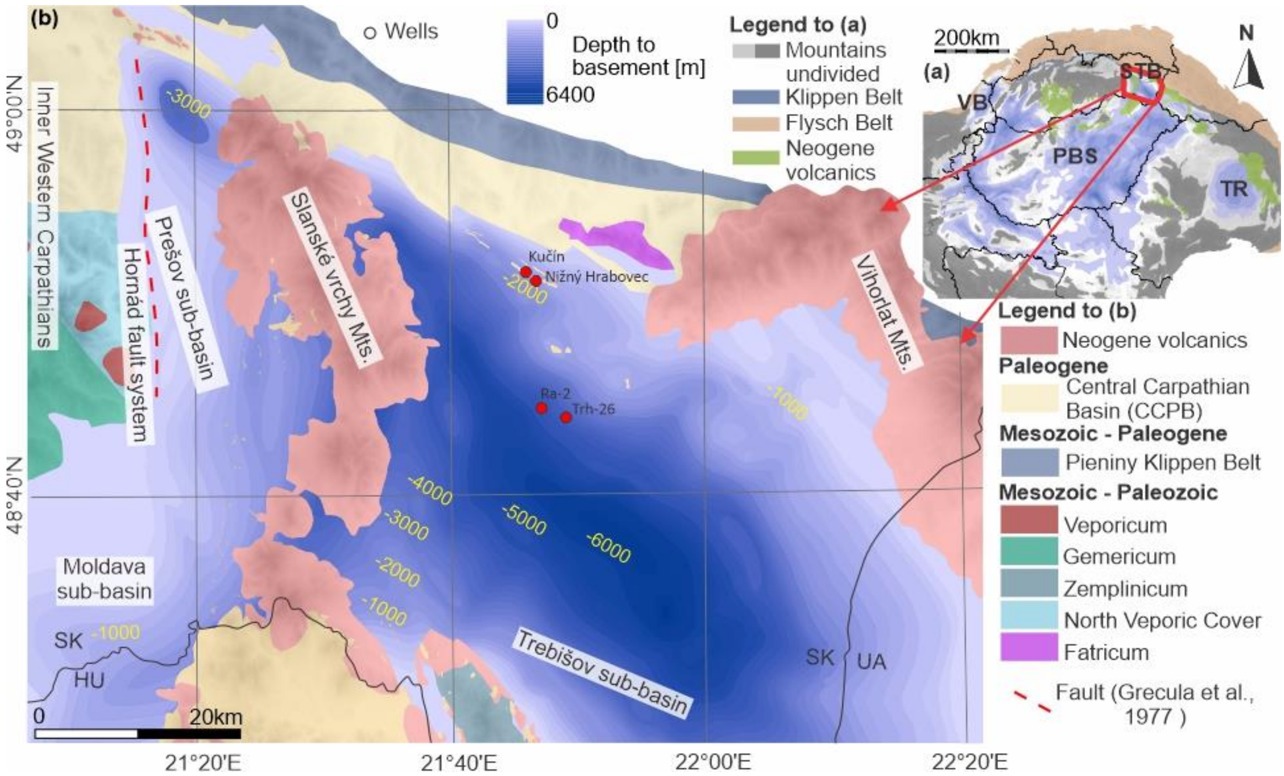


Figure 1. *Location map. a) Map of the Pannonian Basin System (PBS) with highlighted position of the East Slovak Basin (ESB), Vienna Basin (VB), and Transylvanian Basin (TR). b) Map of the ESB with location of key wells and outcrops. Modified after Subová et al. (2022, 2024a,b).*

reworked parts, the number of crystal phases increases, and garnet (almandine) appears.

Quantitative X-ray diffraction analysis shows that surface samples contain up to 6 wt.% of plagioclase crystals, except in coarse-grained, reworked intervals, where plagioclase content increases up to 30 wt.%. Clinoptilolite forms around 70–80 wt.% but decreases to 50–60 wt.% in the reworked layers; similarly, the SiO_2 content decreases from 12–15 wt.% to around 7 wt.%. At deep-well samples, the plagioclase content ranges between 11–16 wt.%, while analcime and SiO_2 content is approximately 21 wt.% and 42 wt.%, respectively. Although these values may be influenced by the degree of alteration, they also reflect grain-size characteristics. The overall trend suggests that the eruption center was likely located to the south of the surface outcrop sites.

Another diagenetic feature observed in all samples is the presence of authigenic K-feldspar (Or_{99-100}), It forms overgrowths on plagioclase and also occurs as pore- and fissure-filling material, indicating post-depositional tectonic processes (Fig. 2).

3.2. Depositional mechanism

The presence of fossil shells, plant debris, substantial deposit thickness, and locally sorted layers suggests a submarine depositional environment, consistent with the surrounding sedimentary context. These features are comparable to modern shallow-marine volcanic eruptions, where eruptive material is rapidly remobilized into gravity flows, producing thicker deposits than those formed in subaerial settings (e.g., Druitt et al., 2024; Metcalfe et al. 2025). Further evidence supporting gravity-flow transport is provided by plant impressions and charred wood fragments observed along bedding planes in the Kučín Quarry. These features indicate the rapid burial of vegetated material, consistent with syn-eruptive deposition by gravity-driven flows in a shallow-marine or proximal nearshore environment.

Due to varying degrees of diagenetic alteration of volcanic glass shards, direct comparison between samples is challenging. However, the samples exhibit consistent plagioclase composition and show similar zircon trace element patterns and U–Pb age data. The observed textures and structures, along with uniform plagioclase chemistry, zircon geochemistry, and new geochronological results, all suggest a common volcanic source for both the well and outcrop samples. Zircon U–Pb age data and volume estimates suggest that an additional distinct larger silicic eruption took place in the early Badenian beside the so far published ones (e.g., Demjén, Harsány, and BD horizons, Lukács et al., 2018, 2021, 2024; Brlek et al., 2024) in the Carpathian–Pannionian region.

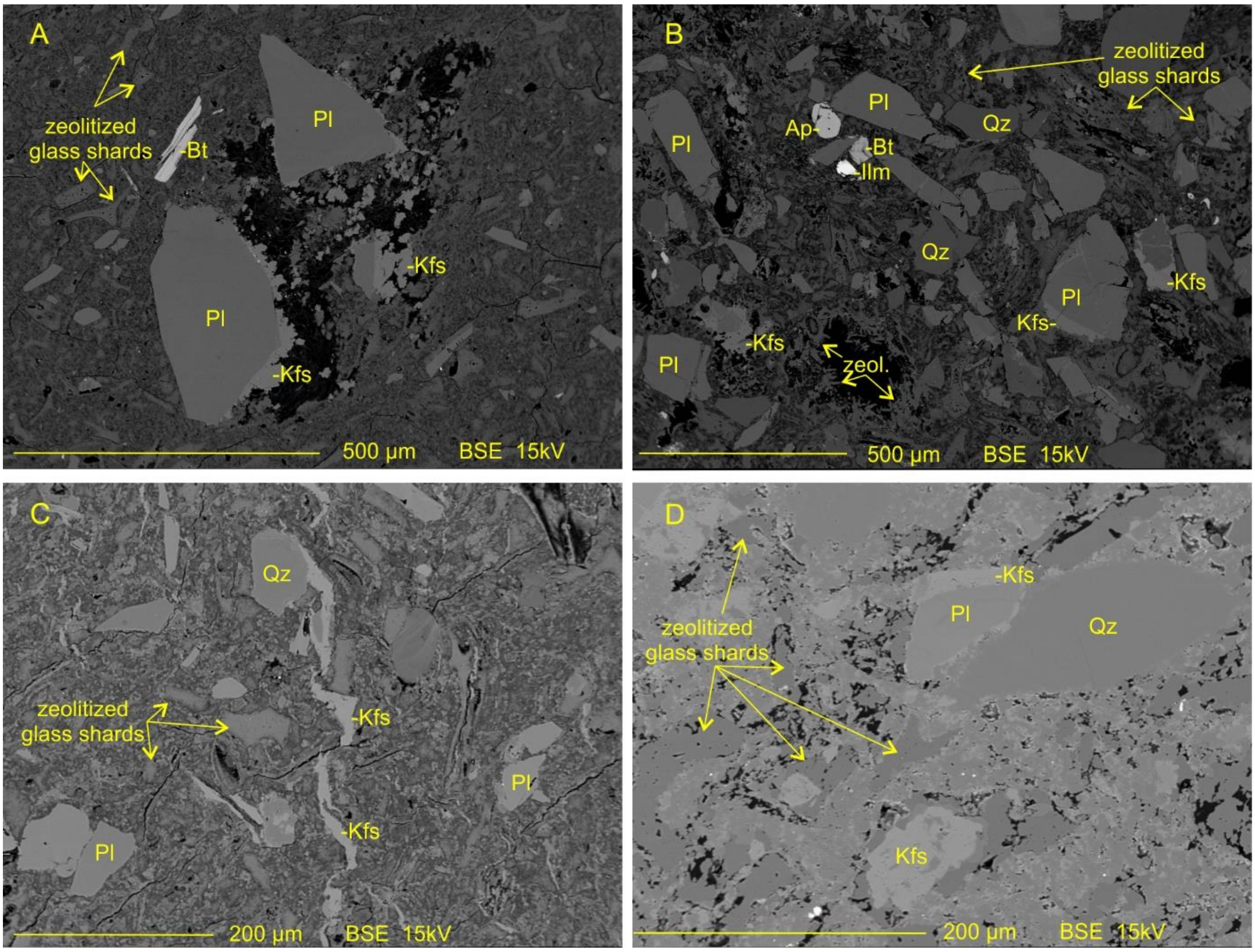


Figure 2. *BSE images of zeolitized tuff (Pl-plagioclase, Kfs-orthoclase, Bt-biotite, Qz-quartz, Ap-apatite, Ilm-ilmenite): a) fine tuff from Nižný Hrabovec Quarry b) coarse tuff from Nižný Hrabovec Quarry, b) fine tuff from Kučín Quarry d) tuff from Trhovište-26 well (depth 2200 m).*

4. Conclusions

The Hrabovec Tuff Member represents a regionally extensive and economically important zeolitized pyroclastic deposit in the East Slovakian Basin. Its consistent mineralogical and geochemical characteristics, despite varying degrees of alteration, support a common volcanic origin of the outcrop and well samples. The observed sedimentary structures and fossil content indicate a submarine depositional setting, compatible with syn-eruptive gravity flow-dominated deposition from shallow-marine environment. The volcanic eruption occurred at the end of the Lower Badenian, and represent additional distinct larger silicic eruption in the Carpathian–Pannonian region. However, the tuff continues further into the basin, and it remains to be clarified whether the remaining occurrences belong to the same or different eruptions.

Acknowledgements

This project is funded by the Slovak Research and Development Agency under contract APVV-23-0227; by VEGA 1/0336/25; by NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V04-00127 and by the Hungarian National Research, Development and Innovation Office (No. 145905). This work is also supported by the MTA–HUN-REN CSFK Lendület "Momentum" Pannonian Volcano Research Group.

References

Brlek M., Trinajstić N., Schindlbeck-Belo J.C., Kutterolf S., Vukovski M., Guillong M., Markovic S., Šuica S., Wang K.-L., Lee H.-Y., Gaynor S.P., Brčić V., Mišur I., Grizelj A., Kurečić T., Milošević M., Baranyi V., Kukoč D., Gilg H.A., Georgiev S. & Lukács R. (2024): International Journal of Earth Sciences, 113, 1427–1455.

Druitt T., Kutterolf S., Ronge T.A., Hübscher Ch., Nomikou P., Preine J., Gertisser R., Karstens J., Keller J., Koukousioura O., Manga M., Metcalfe A., McCanta M., McIntosh I., Pank K., Woodhouse A., Beethe S., Berthod C., Chiyonobu S., Chen H., Clark A., DeBari S., Johnston R., Peccia A., Yamamoto Y., Bernard A., Perez T.F., Jones Ch. Joshi K. B., Kletetschka G., Li X., Morris A., Polymenakou P., Tominaga M., Papanikolaou D., Wang K.-L. & Lee H.-Y. (2024): Communications Earth and Environment, 5, 24.

Lukács R., Harangi Sz., Guillong M., Bachmann O., Fodor L., Buret Y., Dunkl I., Sliwinski J., von Quadt A., Peytcheva I. & Zimmerer M. (2018): Earth-Science Reviews, 179, 1–19.

Lukács R., Guillong M., Bachmann O., Fodor L. & Harangi Sz. (2021): Frontiers in Earth Science, 9, 615768

Lukács R., Guillong M., Szepesi J., Szymanowski D., Portnyagin M., Józsa S., Bachmann O., Petrelli M., Müller S., Schiller D., Fodor L., Chelle-Michou C. & Harangi Sz. (2024): Gondwana Research, 130, 53–77.

Metcalfe A., Druitt T., Pank K., Kutterolf S., Preine J., Kelfoun K., Hübscher C., Nomikou P., Ronge T.A., Chiyonobu S., Koukousioura O., Woodhouse A., Beethe S., Manga M., McIntosh I., Tominaga M., Berthod C., Chen H., Clark,A., DeBari S., Gertisser R., Johnston R., Peccia A., Yamamoto Y., Bernard A., Fernandez Perez T., Jones C.K., Joshi K.B., Kletetschka G., McCanta M., Morris A., Polymenakou P., Li X., Nedelec J.-M., Lee H.-Y. & Papanikolaou D. (2025): Science Advances, 11, eads9642

Šamajová E. (1997): In: Kirov G.N., Filizova L. & Petrov O. (eds.): Natural Zeolites – Sofia ’95, Sofia–Moscow: Pensoft Publishers, 215–226.

Slávik J. (1968): Geologické práce, Zprávy, 44-45, 215–239.

Subová V., Rybár S., Šarinová K., Hudáčková N., Jamrich M., Sliva Ľ., Šály B. & Hlavatý I. (2022): Geologica Carpathica, 73, 319–352.

Subová V., Rybár S., Hudáčková N., Jamrich M., Jourdan F., Mayers C. & Sliva Ľ. (2024a): Geologica Carpathica, 75, 243–269.

Subová V., Rybár S., Sliva Ľ. & Šály B. (2024b): Geological Society, London, Special Publications, 555. In: Tari G.C., Kitchka A., Krézsek C., Lučić D., Markič M., Radivojević D., Sachsenhofer R.F. & Šujan M. (eds.): The Miocene Extensional Pannonian Superbasin, Volume 2: Geoenergy Exploration.

Tschegg C., Rice A.H.N., Grasemann B., Matiasek E., Kobulej P., Dzivák M. & Berger T. (2019): Economic Geology, 114, 1177–1194.

Ustaszewski K., Schmid S.M., Fügenshuh B., Tischler M., Kissling E. & Spakman W. (2008): Swiss Journal of Geosciences, 101(Suppl. 1), S273–S294.

Vass D., Elečko M., Janočko J., Karoli S., Pereszlényi M., Slávik J. & Kaličiak M. (2000): Slovak Geological Magazine, 6, 377–407.

Vass D. (2002): Lithostratigraphy of Western Carpathians: Neogene and Buda Paleogene. State Geological Institute of Dionýz Štúr, 1–202.

DO PETROLEUM INCLUSIONS GENUINELY REFLECT THE ORIGINAL FLUID COMPOSITION?

Félix Schubert[1]*, Lili Ladányi[1,2], Péter Koroncz[3], Sándor Körmös[4], Gábor Steinbach[2] & Tivadar M. Tóth[1]
[1] University of Szeged, Department of Geology, Szeged, Hungary
[2] HUN-REN Biological Research Centre, Szeged, Hungary
[3] Mecsekérc Ltd., Pécs, Hungary
[4] MOL Hungarian Oil and Gas Plc. Group, Budapest, Hungary
* E-mail: schubert@geo.u-szeged.hu

In recent decades, fluid reservoirs, hosted in carbonate, have become increasingly important in fluid mining; therefore, acquiring a detailed understanding of the conditions of fluid migration within them is essential for both exploration and exploitation activities. The physical and chemical properties of fluids present in a rock body can be preserved for millions of years by fluid inclusions trapped in minerals. They can thus provide information about the circumstances under which the rocks were formed and about subsequent effects, such as fluid migration under different physico-chemical conditions. The trapping of fluid inclusions – in minerals suitable for preservation – is possible across a wide range of temperatures and pressures, enabling them to reveal information about the conditions of rock formation from the Earth's mantle to the surface.

The most crucial information carried by fluid inclusions is the composition and density of the trapped fluid. However, the latter can only be determined if the inclusions represent an isochoric (constant volume) and isoplethic (constant composition) system after entrapment (Diamond, 2003). In other words, the rock containing the fluid inclusion assemblage was not affected by subsequent effects (such as temperature, pressure changes or deformation), which can often cause unknown and consequently uncontrollable changes in the composition and/or density of fluid inclusions (Goldstein & Reynolds, 1994). These fluid remnants can be trapped by various mechanisms, even within the same mineral. This results in the formation of primary (simultaneous with the formation of the given mineral phase) and secondary (along cracks that have already formed in the precipitated mineral, resulting from their healing) fluid inclusion assemblages.

Fluid inclusions containing petroleum trapped in sedimentary basin rocks not only provide information about the source rock, maturity, and degradation of hydrocarbon fluids, but also—along with co-genetic aqueous inclusions—allow estimation of the temperature and pressure during fluid migration. Petroleum inclusions are highly complex, multi-component systems because of the nature of the hydrocarbon compounds they contain. Therefore, detailed, routine analysis of their chemical composition can only be achieved by opening the inclusion cavities, which means a bulk analysis of all fluid inclusion assemblages in the sample.

In recent decades, several authors have noted, and our findings have confirmed, that petroleum inclusions showing markedly different properties (e.g., colour, UV fluorescence properties, liquid-vapour volume ratios) can be trapped very close to one another (Pironon & Bourdet, 2008; Lukoczki et al., 2012). In most cases, this phenomenon occurs in petroleum inclusions trapped in carbonate minerals. Since the routine, indirect examination of petroleum inclusions relies on UV-fluorescent emission, a key question is whether inclusions with different fluorescence indicate multiple fluid migration events with different compositions or whether they formed during trapping or as a result of subsequent processes.

To answer this question, we used crude oil to produce synthetic fluid inclusions in calcite crystals at a temperature of 150 °C and a pressure of 400 bar. This enabled us to compare the fluorescent parameters of crude oil (spectral distribution, fluorescence lifetime, calculated spectral parameters) on a microscopic scale both before and after trapping.

The research was conducted with the support of the National Scientific Research Fund (K-138919).

References

Diamond L.W. (2003): Mineralogical Association of Canada Short Course Series, 32, 55–79.

Goldstein R.H. & Reynolds T.J. (1994): SEPM Short Course Notes, 31, 1–199.

Lukoczki G., Schubert F. & Hámorné V. M. (2012): Bulletin of the Hungarian Geological Society, 142(3), 229–242.

Pironon J. & Bourdet J. (2008): Geochimica et Cosmochimica Acta, 72, 4916–4928.

GEOCHEMICAL AND SPECTROMETRIC CHARACTERIZATION OF NATURAL RADIOELEMENTS (^{238}U, ^{232}TH, AND ^{40}K) IN SOME GRANITOID ROCKS FROM THE CENTRAL EASTERN DESERT, EGYPT

Aya Shereif[1,2]*, Mohamed Heikal[2], Abdel Salam Abu El Ela[2], Mokhles Azer[3], Ahmed El Shabasy[4], Ahmed Masoud[2] & Árpád Csámer[1,5]

[1] University of Debrecen, Department of Mineralogy and Geology, Debrecen, Hungary
[2] Tanta University, Department of Geology, Tanta, Egypt
[3] National Research Centre, Department of Geological Sciences, Egypt
[4] Nuclear and Radiological Regulatory Authority, Department of the Radiation Protection, Egypt
[5] University of Debrecen, Cosmochemistry and Cosmic Methods Research Group, Debrecen, Hungary
* E-mail: aya.salah@science.unideb.hu

Granitic rocks are extensively used in construction and architecture, from interior décor to exterior facades and paving. Their accessory minerals (zircon, monazite, xenotime, allanite, apatite, and K-feldspar) serve as natural reservoirs of radionuclides (U, Th, and K). Using such materials can raise ambient radiation exposure; therefore, systematic assessment of their radiological hazards is crucial to ensure compliance with health and safety regulations.

Wadi El-Nabi' mining district (≈120 km^2) forms an important part of the Marsa Alam region and is geologically linked to the Egyptian Nubian Shield (ENS). It comprises a Precambrian intrusive–extrusive lithotectonic assemblage with diverse lithologies, including ophiolitic serpentinites, bimodal metavolcanic sequences (felsic and mafic), metapyroclastic derivatives, metagabbro–diorite complexes, and younger gabbros. The area also contains monzogranitic and syenogranitic intrusions representing the younger granitoid phase of magmatic evolution.

Field and laboratory radiometric and geochemical analyses were conducted over ~55 km^2 of monzo-syenogranites using RS-230 γ-ray spectrometry, HpGe detectors, and ICP-MS to quantify and interpret the distribution and geochemical behaviour of ^{238}U, ^{232}Th, and ^{40}K. Radiological hazard parameters, were also calculated to assess radiation risks in the monzogranite and syenogranite samples.

RS-230 γ-ray spectrometry shows mean radionuclide concentrations in monzo-syenogranitic samples of 5.1 ppm for eU, 12.76 ppm for eTh, and 4.43% for ^{40}K. HpGe detector analyses indicate average specific activities of ^{238}U, ^{232}Th, and ^{40}K at 29, 34, and 883 Bq/kg, respectively in monzogranites, and slightly higher values of 31, 35, and 890 Bq/kg, respectively in syenogranites. Geochemical analyses further reveal average concentrations of 3.04 ppm ^{238}U, 9.44 ppm ^{232}Th, and 1.82% ^{40}K in the studied monzo-syenogranitic samples.

Geochemical evidence indicates a dominantly magmatic origin for the investigated radionuclides, later overprinted by hydrothermal alterations. The disequilibrium inferred from the D-factor (Uc/Ur) supports this interpretation. ICP-MS analyses yield Th/U ratios of 2.22–4.49 (avg. 2.94 ppm), with the latter falling below the global average (3.8 ppm), suggesting uranium enrichment (Boyle, 2013), and this matches with the radiometric ratios also.

The recorded concentrations indicate that the levels of ^{232}Th and ^{40}K exceed internationally recognized permissible limits (UNSCEAR, 2000). Radiological assessments further demonstrate that parameters such as D_{out}, D_{in}, $AEDE_{in}$, $ELCR_{out}$, $ELCR_{in}$ and $I_γ$ for both monzogranites and syenogranites samples, surpass the recommended safety thresholds. Conversely, the calculated Ra_{eq}, $AEDE_{out}$, H_{ex}, and H_{in} values remain within globally accepted limits.

Accurate data on natural radioisotope concentrations in granitic regions is essential for evaluating radiological conditions, monitoring environmental contamination, and assessing health risks. Such baseline information guides policy decisions and supports long-term radiation hazard mitigation.

References

Boyle, R.W. (2013): Geochemical prospecting for thorium and uranium deposits. Elsevier.

UNSCEAR (2000): Report to General Assembly with Scientific Annexes, United Nations, New York.

ASSIMILATION OF (META-)IGNEOUS MATERIAL: INSIGHTS FROM LA-ICP-MS TRACE ELEMENT MAPPING OF GARNETITES FROM SOUTH APUSENI ANDESITES

Adriana Stoica* & Gheorghe Popescu
University of Bucharest, Faculty of Geology and Geophysics, Doctoral School of Geology, Bucharest, Romania
* E-mail: stoica.mala@gmail.com

In this study, we integrate fine-scale petrographic evidence with quantified LA-ICP-MS trace element raster mapping to investigate garnetite lenses hosted in Neogene andesites from the Almasul-Mare area, South Apuseni Mountains, Romania.

The garnetites occur as elongated enclaves, composed predominantly (>80 vol.%) of tightly packed, locally annealed garnet crystals, ranging from euhedral to sub-rounded morphologies, with interstitial plagioclase and chlorite.

Garnet crystals host mineral inclusions such as plagioclase, Fe–Ti oxides, apatite, zircon, and rare anhedral titanite. Plagioclase inclusions consistently show higher anorthite content (An_{75}) than their interstitial counterparts (An_{43}).

Trace element distribution maps in garnetite lenses reveal abrupt concentration gradients. This compositional variation correlates with the spatial occurrence of garnet grains within the garnetite. Garnets from the central domains are depleted in HREEs, Y, and Ti, but enriched in Sm, Sc, V, and Zr. In contrast, outer zones are notably enriched in HREEs and Y, with CI-normalized concentrations elevated by up to an order of magnitude.

The presence of euhedral apatite and zircon, together with melt and fluid inclusions in garnet, provides compelling evidence that garnet coexisted with both silicate melt and fluid phases. In contrast, chlorite (interpreted as a secondary phase replacing primary mafic minerals), resorbed high-An plagioclase, and rare titanite may represent relict phases of the protolith, partially consumed during incongruent melting.

We interpret these garnetites as the product of deep crustal anatexis of a mafic to intermediate protolith of igneous parentage, producing peritectic garnet via mafic mineral-consuming reactions. The depleted trace element signatures in the inner garnetite domains reflect this early peritectic growth, controlled by progressive destabilisation and/or the limited availability of compatible elements from the reactive minerals. Subsequent extraction of peritectic garnet clusters from the source resulted in the growth of igneous garnet envelopes (enriched in HREEs and Y, facilitated by a high contribution from the hosting magma).

These findings highlight the potential of garnet-rich enclaves to archive petrogenetic processes, including localised peritectic reactions and crustal assimilation, thus providing key constraints on the differentiation and hybridization of calc-alkaline magmas.

INSIGHTS INTO THE STRUCTURAL EVOLUTION AND MINERAL VEIN DEVELOPMENT IN THE JUHHODÁLYVÖLGY MARBLE (ÓFALU, GOLDGRUND VALLEY)

Döme Zsombor Szabó[1]*, Elemér Pál-Molnár[1] & Ervin Hrabovszki[1,2]
[1] University of Szeged, Department of Geology, Szeged, Hungary
[2] University of Debrecen, Department of Mineralogy and Geology, Debrecen, Hungary
* E-mail: szabodome06@gmail.com

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 main orogenic phase of the Variscan cycle in the Carboniferous. The aim of this study is to investigate a representative lithology of the Ófalu Metamorphic Complex, the Juhhodályvölgy Marble, to better understand the hydrogeological and structural development of the complex (Dabi et al., 2009, 2011), as well as the broader geological evolution of the Mecsekalja Zone. To achieve this, mineral veins were analysed in detail, as fracture systems observed in outcrops, together with their associated vein mineral assemblages, provide valuable insights into deformation events and related fluid migration processes. In addition to the analysis of mineral veins in the Juhhodályvölgy Marble, field observations were carried out on the Studervölgy Gneiss and Kövespatak Quartz Phyllite exposed in the Goldgrund Valley, with particular focus on metamorphic and brittle structural elements.

The orientation of metamorphic foliation and fracture planes was systematically evaluated and visualised using stereographic projections. All three lithologies display a consistent NE–SW striking foliation, dipping either to NW or SE. This structural coherence across the distinct units indicates similar deformation history and suggests that these rocks were already spatially associated prior to the late Carboniferous to early Permian metamorphism (270–303 Ma), as constrained by $^{40}Ar/^{39}Ar$ ages (Lelkes-Felvári et al., 2000). This interpretation is consistent with the previous structural model proposed by Balla & Gyalog (2009). It is possible that this pre-existing structural framework was later reactivated and modified during subsequent deformation phases.

Rock samples collected from the Juhhodályvölgy Marble were analysed using polarizing and cathodoluminescent microscopy, as well as Raman microspectroscopy. These analytical techniques enabled the detailed investigation of the samples' microstructural and textural characteristics, which are essential for understanding the types of fluid and material transport and the formation of the mineral veins (Bons et al., 2012).

Micro-scale analyses combined with orientation data distinguish two generations of veins in the Juhhodályvölgy Marble. One set of veins aligns with the NE–SW striking foliation, while the other is oriented nearly perpendicular to it. Most veins display characteristic syntaxial textures, composed of elongate blocky and blocky calcite crystals. Cathodoluminescent analysis reveals 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 calcite precipitation along vein walls with orange luminescence, followed by a later generation of calcite overgrowths displaying dark blue luminescence. The observed growth zonation in both vein generations likely reflects temporal variations in the Fe^{2+}/Mn^{2+} ratio of the mineralising fluids.

In summary, the NE–SW striking veins in the Juhhodályvölgy Marble record a single phase of calcite precipitation, while the NW–SE striking veins reflect two distinct episodes of fluid migration. Based on this, the host rock experienced at least two discrete tectonic and fluid migration events. These observations provide a solid basis for future studies, such as fluid inclusion micro-thermometry and stable isotope analyses, which may further refine our understanding of the petrogenetic and tectonic evolution of the Ófalu area.

References

Balla Z. & Gyalog L. (eds.): A Mórágyi-rög északkeleti részének földtana. Hungarian Geological Institute, Budapest.

Bons P.D., Elburg, M.A. & Gomez-Rivas E. (2012): Journal of Structural Geology, 43, 33–62.

Dabi G., M. Tóth T. & Schubert F. (2009): Bulletin of the Hungarian Geological Society, 139, 3–20.

Dabi G., Siklósy Z., Schubert F., Bajnóczi B. & M. Tóth T. (2011): Geofluids, 11, 309–327.

Lelkes-Felvári Gy., Árkai P., Frank W., Nagy G. (2000): Acta Geologica Hungarica, 43, 65–84.

M. Tóth T., Kovács G., Schubert F. & Dályai V. (2005): Bulletin of the Hungarian Geological Society, 135, 331–353.

A CO_2 ISLAND IN A HYDROCARBON SEA – THE CASE STUDY OF THE GAS EMISSIONS OF SLĂNIC MOLDOVA, EASTERN CARPATHIANS, ROMANIA

Réka Szalay[1]*, Boglárka-Mercedesz Kis[1], Szabolcs-Attila Kövecsi[1] & Andreea-Rebeka Zsigmond[2]
[1] Babeș-Bolyai University, Department of Geology, Cluj-Napoca, Romania
[2] Sapientia Hungarian University of Transylvania, Department of Environmental Science, Cluj-Napoca, Romania
* E-mail: roland.szalay@ubbcluj.ro

Recent research on greenhouse gases increasingly highlights that CO_2 mobilized from tectonically and seismically active areas significantly contributes to the annual budget of natural CO_2 outgassing (Fischer & Aiuppa, 2020). Methodological advancements in the early 2000s, including the development of instruments utilizing infrared, electrochemical, and remote satellite sensing technologies, have enabled the high-resolution mapping of geochemical data and soil gas fluxes on-site and in real-time, in a cost-effective manner (Fischer & Aiuppa, 2020). This new approach has allowed researchers to gain detailed insights into the origin, chemical composition, and gas flux data of smaller, locally controlled tectonic CO_2 or CH_4 anomaly zones.

In Romania, within the Eastern Carpathians, CO_2-dominated natural gas emissions are observed, occurring in both dry and wet forms. Research on these gas emissions dates back to the 19th century and continues to the present day (e.g., Ilosvay, 1895; Airinei & Pricăjan, 1970; Vaselli et al., 2002). A summary of these studies provides insights into the history, chemical composition of the gases, their associated environments, and their geological origins. In 1970, Airinei described the region as the mofetic aureole of Carpathians. Additionally, Airinei & Pricăjan (1970) noted a potential connection between the surface appearance of the gases and the structural geological elements of the mofetic area.

The Eastern Carpathian fold and thrust belt is one of the world's oldest and most prolific oil and gas-producing regions of the country (Paraschiv, 1979). By 1857, the petroleum industry in this area had advanced significantly, with crude oil production reaching around 275 tonnes per year (Paraschiv, 1979). To gain a deeper understanding of tectonic emissions in the Eastern Carpathians, our objective is to investigate soil CO_2 flux along major active fault systems, such as the Trotuș fault and the surrounding areas of Slănic Moldova. The town of Slănic Moldova is situated within the Paleogene flysch complex of the Eastern Carpathians. Slănic Moldova is a region characterized by complex tectonic features, including pronounced Flysch fold geological boundaries, minor local faults, and an active strike-slip fault system extending over several hundred kilometers where best-preserved conditions for hydrocarbon reservoirs are found. To date, around 30 oil fields and 2 hydrocarbon gas fields have been identified primarily located between the Bistrița and Slănic-Oituz tectonic half-windows, where they are protected by the Tarcău nappe's tectonic overburden (Paraschiv, 1979).

We performed over 300 measurement points in a pre-defined grid during the autumn period of 2023 and 2024 (the driest and most stable weather conditions in Romania typically occur during this season). Our preliminary results reveal a west-eastward CO_2 flux anomaly, with the highest CO_2 flux observed being an order of magnitude greater at 1120 $g/m^2/day$, compared to the lowest environmental flux of 1 $g/m^2/day$ in the studied area. We have also sampled and measured the mineral water springs of the area, which exhibit very high salinity (exceeding 5000 mg/l) and mainly dominated by Na, Cl and HCO_3 ions.

References

Airinei St. & Pricajan A. (1970): Buletinul Societăți Științifică Geologică Română 12, 125–135.

Fischer T.P. & Aiuppa, A. (2020): Geochemistry, Geophysics, Geosystems, 21, e2019GC008690

Ilosvay L. (1895): Természettudományi Társulat, Budapest.

Paraschiv D. (1979): Romanian oil and gas fields. Editura Academica, Bucharest.

Vaselli O., Minissale A., Tassi F., Magro G., Seghedi I., Ioane D. & Szakács A. (2002): Chemical Geology, 182(2-4), 637–654.

PETROLOGY, ZIRCON U–PB DATING, AND CORRELATIONS OF VARISCAN S-TYPE GRANITOIDS IN THE TISZA MEGA-UNIT

Máté Szemerédi[1,2]*, István Dunkl[3], Dóra Georgina Miklós[4], Réka Lukács[2,5], Marija Horvat[6], Krisztina Sebe[7], Árpád Máthé[1,8], Zoltán Kovács[9], Zoltán Máthé[10], Zsolt Benkó[11,12], János Szepesi[2,11], Szabolcs Harangi[2,5] & Elemér Pál-Molnár[1]

[1] University of Szeged, Department of Geology, 'Vulcano' Petrology and Geochemistry Research Group, Szeged, Hungary
[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, Institute for Geological and Geochemical Research, HUN-REN Research Centre for Astronomy and Earth Sciences, Budapest, Hungary
[3] University of Göttingen, Department of Sedimentology & Environmental Geology, Göttingen, Germany
[4] Hungarian National Museum, National Archaeological Institute, Archaeometry Laboratory, Budapest, Hungary
[5] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[6] Croatian Geological Survey, Department of Geology, Zagreb, Croatia
[7] HUN-REN–MTM–ELTE Research Group for Paleontology, Budapest, Hungary
[8] Supervisory Authority of Regulatory Affairs, Department of Mineral Resource Inventory and Mining Revenue, Budapest, Hungary
[9] HUN-REN Centre for Energy Research, Budapest, Hungary
[10] MECSEKÉRC Ltd, Pécs, Hungary
[11] HUN-REN Institute for Nuclear Research, Geochronology Group, Debrecen, Hungary
[12] University of Debrecen, Department of Mineralogy and Geology, Debrecen, Hungary
* E-mail: szemeredi.mate@gmail.com

Two-mica leucogranites, granodiorites, and their variably deformed/metamorphosed varieties are found in several parts of the Tisza Mega-unit, including the Apuseni Mts (Codru-Moma and Highiş Mts), southern Transdanubia (Mecsek Mts), the Slavonian Mts (Papuk Mt), and various basement areas in the eastern Pannonian Basin (such as the Battonya–Pusztaföldvár Basement Ridge and Algyő–Ferencszállás Basement High). Despite their similar petrographic characteristics, the relationships among these rocks have remained unclear due to limited geochemical and geochronological data. To better understand their petrogenesis, geodynamics, age constraints, and both local and regional correlations, this study conducted detailed mineralogy and petrography, whole-rock major and trace element geochemistry, and zircon U–Pb dating on samples from these areas.

Many of these samples show evidence of post-magmatic alterations, including Cretaceous (~106 Ma) and Miocene (~16 Ma) hydrothermal effects and Alpine deformation/metamorphism, as supported by sericite or illite K/Ar ages and microtextural observations, respectively. We found a significant amount of discordant and Pb loss affected zircon U–Pb data, and zircon inheritance (i.e., xenocrysts) is also a common feature in the studied samples. Based on the limited reliable age data available, we identified at least three distinct periods of S-type granitoid magmatism within the Tisza Mega-unit. The oldest, Early Ordovician age (~480–470 Ma) was obtained from orthogneisses in the Papuk Mt which could represent a syn-collisional or post-orogenic geotectonic setting. These monzogranites were affected by subsequent metamorphism, resulting in their gneissic structure. Late Devonian (~370 Ma) to Early Carboniferous (~360–340 Ma) ages characterize granitoids from the Apuseni Mts (Codru granodiorites) and the Battonya–Pusztaföldvár Basement Ridge (Battonya granitoids) which display slab break-off features and may indicate a transition from subduction to continental collision. Their similar whole-rock geochemistry suggests local correlations between these formations, which also closely resemble analogous granodiorites in the Western Carpathians. The youngest, Middle Permian age (~270 Ma) was calculated for monzogranite pebbles found in the Lower Miocene siliciclastic sequences (Szászvár Formation) in the western Mecsek Mts. These granites were most likely associated with a post-collisional setting. Orthogneisses from the Algyő–Ferencszállás basement area could not be dated; however, they may represent a syn-collisional or post-collisional setting. At a regional scale, the Paleozoic igneous formations in the Tisza Mega-unit show correlations with those of the Western Carpathians, where analogous Early Ordovician, Early Carboniferous, and Middle Permian igneous events were also documented.

This study was supported by the NRDI Fund (projects K131690 and FK148576) and by the University Research Scholarship Programme (project EKÖP-24-4-SZTE-633).

POLISHED STONE TOOL ASSEMBLAGE OF LATE NEOLITHIC ÖCSÖD-KOVÁSHALOM SITE

Veronika Szilágyi[1]*, Kata Furholt[2], Zoltán Kovács[1], Zsolt Kasztovszky[1], András Füzesi[3], Pál Raczky[4], Máté Biró[5], Zsófia Farkas[6], Tamás Sági[6], Sándor Józsa[6] & György Szakmány[6]
[1] HUN-REN Centre for Energy Research, Budapest, Hungary
[2] Christian-Albrechts-Universität zu Kiel, Institute of Pre- and Protohistoric Archaeology, Kiel, Germany
[3] MNM KK Hungarian National Museum, Budapest, Hungary
[4] Eötvös Loránd University, Institute of Archaeological Sciences, Budapest, Hungary
[5] Eötvös Loránd University, Department of Mineralogy, Budapest, Hungary
[6] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
* E-mail: szilagyi.veronika@ek.hun-ren.hu

Our research, as a subsequent study on stone tool archaeometry, aims to identify the raw materials of the polished stone tools from the Late Neolithic (Tisza culture, turn of the 6th–5th millennium BC, Middle Tisza region) tell-like settlement of Öcsöd-Kováshalom and to examine the provenance of the finds. A total of 193 polished stone tools, excavated between 1980 and 1985, were subjected to macroscopic petrographic and magnetic susceptibility (MS) examination. Detailed examinations were then conducted on a smaller (44-piece) sample set using destructive and non-destructive petrographic-geochemical methods (OM, SEM-EDS, PGAA).

The assemblage consists of highly fragmented stone tools, predominantly without perforation (chisels, axes, shoe-last axes), which can be classified into 10 major petrographic types, alongside other lithologies occurring as individual samples. The predominant rock type (40%, 78 pcs) is metadolerite-metamicrogabbro, which forms a unified group in terms of its macro- and microscopic petrographic characteristics (color, texture, mineralogical composition), although MS values fall into three ranges (low, medium, high). In addition to the original rock-forming phases (pl+aug+igneous am±ol+ilm/mt), low-grade metamorphic minerals (am+ab+ep/zoi+pmp) may also occur. The tools may presumably originate from several raw material sources (Szarvaskő, Mureș Valley, possibly the Dinaric-Vardar zone, Szilágyi et al., 2022).

Greenschist–amphibolite is the second most common type (16%, 31 pcs), representing a petrographically heterogeneous group (grain size, texture, mineral composition: am+ab/pl+chl±q±kfs±ep). The exact origin is difficult to determine due to its regional distribution and common formation processes. Greenschist–amphibolite occurrences in the Western Carpathians can be assumed as potential raw material sources, but the poorly researched rocks of the Apuseni Mts. can also be taken into account (Szakmány et al., 2018).

Contact metabasite and hornfels are each represented by 22 specimens (11% each). Both are types that can be macroscopically identified with high confidence and are common polished stone tool raw materials, characterized by a relatively unified tool form. The metabasites derive from the Krkonoše Jizera Crystalline Complex in the Czech Republic, while the hornfels originates from the Rusca Mts. or the southern part of the Apuseni Mts.

Subordinate rock types include acidic–neutral metamagmatite (6%, 11 pcs), andesite (4%, 8 pcs), basalt (2.5%, 5 pcs), limestone (2%, 4 pcs), and sandstone (1.5%, 3 pcs). The igneous rocks can be linked to the Triassic formations in the eastern Bükk Mts., the pyroxene andesites of the Tokaj Mts. (possibly also Mátra Mts.), the Karancs–Medves basalts, and the alkaline dolerites of the Mecsek Mts. No exact provenance could be determined for the sedimentary rocks. Among the individual stone tools, quartzite/quartzite schist, skarn, serpentinite, chloritite, nephrite, marble, and metamonzodiorite occur.

In the Midde Tisza region of the Great Hungarian Plain, which lacks primary outcrops and is poor in alluvial gravel, the diverse polished stone tool assemblage from Öcsöd-Kováshalom indicates a similarly complex system of relationships as observed at other large Neolithic sites (e.g., Polgár-Csőszhalom, Hódmezővásárhely-Gorzsa). Our study confirms the use of both eastern (Apuseni Mts.) and northern (Western Carpathians) regional, and long-distance (Krkonoše Jizera Crystalline Complex) raw material supply.

References

Szakmány Gy., Józsa S., Kovács Z., Fehér K., Fábián Sz. (2018): 9th Assembly of Petrology and Geochemistry, Abstract Book, 159.

Szilágyi V., Szakmány Gy., Józsa S., Szilágyi K., Harsányi I., Kasztovszky Zs., Kovács Z. (2022): 12th Assembly of Petrology and Geochemistry, Abstract Book, 130.

CHARACTERIZATION OF MEDIUM-TEMPERATURE FIRED IRON-FREE CLAYS BASED ON MICROTEXTURE AND MINERALOGICAL COMPOSITION

Veronika Szilágyi[1]*, Zoltán Kovács[1] & Péter Kónya[2]
[1] HUN-REN Centre for Energy Research, Budapest, Hungary
[2] Supervisory Authority for Regulatory Affairs, Budapest, Hungary
* E-mail: szilagyi.veronika@ek.hun-ren.hu

Birefringent microtexture (b-fabric) phenomena, well known in soil science (Stoops, 2003), can also be observed in the clayey matrix of fired ceramics. Due to the raw material modifications carried out during ceramic production (kneading, mixing of clays or clay with sand), this fact is not evident (Josephs, 2005). There are no experimental studies on how kneading changes the primary clay microtexture, however, characteristic fabric types can be identified in ceramics, which are necessarily inherited from the original raw material. This provides an opportunity to identify the initial clay type based on fabric. In addition, we can also obtain information about the formation circumstances of the raw clay.

In this study, microtextural examination of ceramics made from iron-free, light-coloured fired clays is presented in comparison with mineralogical compositional (XRD) and mineral chemistry (SEM-EDS) data. Based on this, we developed categories that will be compared with the properties of known raw material types for future identification.

The iron-free/iron-poor clayey pastes of the observed light-coloured archaeological ceramics from Hungarian Medieval – Early Modern Age archaeological sites always have kaolinite-illite clay composition or a mixture of their high-temperature transformation products (mainly mullite or amorphous phase) accompanied with clastic components (quartz, feldspars, mica, anatase).

The microtexture of the light-coloured ceramics is always hiatal with pure clayey paste and medium- to coarse-grained aplastics. The following b-fabrics could be identified: mosaic-spackled, monostriated, cross striated, parallel striated and total striated. Most of these fabrics are genetically connected to clays subjected to intensive shrinkage and swelling or illuviation.

The microtextural features observable on BSE images could further refine the categories, however, textural modifications due to medium-temperature firing (700–1000 °C) has to be considered. Thus, except for vitrification phenomena, arrangement of clay particles can be characteristic for the fabric type.

As a result, at least six fabric types of light-coloured ceramics were differentiated and will be subjected to provenance study in the future. Those are necessarily derived from more (probably less than six) clay sources.

References

Josephs R.L. (2005): Geoarchaeology, 20(8), 861–865.
Stoops G. (2003): Guidelines for Analysis and Description of Soil and Regolith Thin Sections, SSSA, Madison.

Noble gas isotopic composition in olivine phenocrysts from Miocene to Pliocene basaltic rocks of the Pannonian Basin

Kende Fülöp Szűcs[1,2]*, Szabolcs Harangi[1,2], Kata Molnár[2,3], Emese Pánczél[1,2], György Czuppon[2], Patrick Konečný[4] & Réka Lukács[1,2]

[1] Eötvös Loránd University, Department of Petrology and Geochemistry, Budapest, Hungary
[2] MTA–HUN-REN CSFK Lendület "Momentum" PannonianVolcano Research Group, HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[3] HUN-REN Institute for Nuclear Research, Geochronology Group, Debrecen, Hungary
[4] State Geological Institute of Dionýz Štúr, Bratislava, Slovakia
* E-mail: szucskende22@gmail.com

Neogene to Quaternary alkaline basalt volcanism in the Pannonian Basin is enigmatic, as it occurred during a phase of thermal relaxation following major continental lithospheric extension (Harangi et al., 2015). Petrogenetic modelling suggests that the majority of magmas formed in the asthenosphere by low degree melting at depths of 80–120 km. A crucial question is why melting was possible at such depths. The composition of the rocks formed by monogenetic basaltic volcanism is highly diverse, ranging from nephelinite, through basanite, and trachybasalt to alkaline basalt, and shows significant variation in the Sr-Nd-Pb isotope ratios (Harangi et al., 2015). Thus, the mantle source of the basaltic magmas may have been heterogeneous, and/or the composition of the primary magmas may have been modified through interactions with the lithospheric mantle via diffusive porous flow. In a monogenetic basalt volcanic field, each volcano contains basalts with unique information about the conditions of its formation and the nature of the asthenosphere.

In this study, we attempt to characterize the compositional features of the source region of basaltic magmas by noble gas isotope ratios in olivine macrocrysts. They are sensitive to any modifications of the dominant peridotite lithology, such as by subduction-related fluids, recycled crustal material or deep mantle plume upwelling. Olivine is a liquidus mineral phase which traps volatiles (mainly carbon dioxide) and various noble gas isotopes in fluid inclusions during growth. The noble gas isotope values, preserved in the primary fluid inclusions, can be subsequently affected by various processes, which can be traced and evaluated by careful modelling calculations, whole-rock and mineral chemistry data. Because of its crystal structure and early crystallization, olivine is the best mineral for such studies.

In this study, for the first time, we present the noble gas isotope characteristics of olivine macrocrysts from the Pannonian Basin and this is complemented by detailed textural and geochemical investigations of the high-Mg olivine crystals. We chose the Bakony–Balaton Upland volcanic field for this study, as the basaltic magmas are mostly primitive and olivine-phyric, and their major, trace element and isotopic compositions have already been published, showing significant variation. The basalt volcanism took place in this volcanic field between 8 and 2.5 Ma. These results provide insights into the nature of the asthenospheric mantle, and we compared them with noble gas isotope data from olivine in peridotite xenoliths representing the local lithosphere.

We were able to produce noble gas isotope results from olivine separates of four basalt localities and of two peridotite xenoliths. Helium isotope ratios, expressed relative to the atmospheric $^{3}He/^{4}He$ ratio (Ra), ranged from 5.9 to 5.3 Ra in samples from Hegyestű and Ság Hill. In these locations, basaltic magmas likely ascended rapidly, minimizing modification of trapped fluids in olivine, preserving the original isotopic signature. Thus, these values may reflect the nature of the asthenospheric source region. In contrast, lower R/Ra values were observed in basalts from Badacsony and Haláp, where magmas likely resided longer in crustal magma reservoirs before eruption. These R/Ra values are lower than those typical in global asthenospheric mantle and are even below the values measured in the local lithospheric xenoliths (6.5–6.9 Ra).

The relatively low noble gas isotope ratios can be explained by a mantle source, potentially influenced by previous subduction-related contamination and/or the presence of recycled crustal material, such as pyroxenite/eclogite.

References

Harangi Sz., Jankovics M.É., Sági T., Kiss B., Lukács R. & Soós I. (2015): International Journal of Earth Sciences, 104, 2007–2032.

TRACES OF A LATE MIOCENE REGIONAL FLUID FLOW IN AN EARLY MIOCENE VOLCANIC SEQUENCE NEAR PAKS (HUNGARY)

Adrienn Tatár[1]*, Ivett Kovács[2], Tibor Németh[3], László Rinyu[4], Zoltán Máthé[5], Christoph A. Hauzenberger[6], Kata Molnár[4], János Szepesi[4] & Zsolt Benkó[1,4]

[1] University of Debrecen, Department of Mineralogy and Geology, Debrecen, Hungary
[2] HUN-REN Research Centre for Astronomy and Earth Sciences, Institute for Geological and Geochemical Research, Budapest, Hungary
[3] University of Pécs, Department of Geology and Meteorology, Pécs, Hungary
[4] HUN-REN Institute for Nuclear Research, Debrecen, Hungary
[5] Mecsekérc Ltd., Pécs, Hungary
[6] Department of Earth Sciences, University of Graz, Graz, Austria
* E-mail: tataradrienn23@gmail.com

Thick andesitic-dacitic volcanic sequences were crossected in two deep boreholes (PAET-29 and PAET-34) drilled in connection with the design of the Paks II nuclear power plant blocks. Unusual, green penetrative celadonitic-smectitic alteration and calcite-chalcedony veins, reported from various segments of the volcanic edifice, were sampled for further mineralogical, geochemical, fluid inclusion, and geochronological studies.

The veins exhibit a symmetric mineralogical zonation: they are rimmed by rhythmic chalcedony, and calcite appears in the core. In the chalcedony rim, disseminated subhedral sphalerite, chalcopyrite, and galena crystals appear in clusters. Glauconite-celadonite was detected in disseminated form within the chalcedony veins. Calcite, in the axis of the veins is subhedral or euhedral, in some segments of the veins. The host andesite/dacite shows dark green celadonitic-galuconitic alteration along the contact with the veins.

Fluid inclusions appear along growth zones of the calcite or as single inclusions in the calcite. The vapor-to-liquid ratio in the two-phase aqueous inclusions is homogeneously 10%. Homogenization of the vapor into the liquid phase ranges from 73 to 79 °C (n=9) for FIA I (fluid inclusion assemblage) and 115-140 °C (n=10) for FIA II. Salinities (3.5-4.5 NaCl equiv. wt%) of the two assemblages do not differ significantly. Clumped isotope analysis of the calcite indicates a crystallization temperature for the calcite at 79±4 °C. The almost identical temperatures suggest that the homogenization temperatures of FIA I can be accepted as trapping temperatures. The estimated pressure of vein formation ranges from 1 to 200 bar, corresponding to very shallow conditions (0-200 m) below the paleo-water table.

Stable C and O isotope analysis was performed on a single euhedral calcite sample, and the result was compared with other calcite vein systems from the neighboring regions. The $\delta^{18}O_{VPDB}$=-14.9‰ is in the range of calcite-barite-fluorite-sulfide veins of Miocene age, reported from the NE segment of the Transdanubian Mountain Range (Poros et al., 2013). In contrast, the $\delta^{13}C_{VPDB}$=-21.54‰ indicates a significant negative shift and proves organic carbon contribution to the parent fluids of the veins. Similar negative stable carbon isotope values of crude oil ($\delta^{13}C_{VPDB}$<25‰) from various hydrocarbon deposits of the Great Hungarian Plain were reported by Fekete & Sajgó (2011) and from basinal fluids by Varsányi et al. (1997).

Glauconite was separated from the veins and from the altered host rock for K/Ar radiometric dating to determine the age of the fluid circulation. The age of the host volcanic system was dated to be early Miocene (19.4—20.8 Ma) by zircon U/Pb (Harangi, 2016) and biotite K/Ar dating methods. Various glauconite grain size fractions (<1; 2 µm) yielded identical ages of 9.7-10.1 Ma, indicating a late Miocene age for the fluid circulation.

The preliminary data are in line with a Miocene regional, basin-scale, hydrocarbon-bearing fluid flow model by Poros et al. (2011). Contrary to the expected classical alteration features of a volcanic-epithermal system, the alteration cannot be directly related to the early Miocene activity of the host volcanic system.

References

Fekete J. & Sajgó Cs. (2011): Central European Geology 54(1-2), 5–13.

Harangi Sz. (2016): Petrological, geochemical, volcanological, petrogenetic and geodynamic evaluation of rock samples PAET-29 and PAET-34 by deep drillings, Research report 1–34.

Poros Zs., Mindszenty A., Molnár F., Pironon J., Győri O., Ronchi P. & Szekeres Z. (2011): International Journal of Earth Sciences, 101, 429–452.

Varsányi I., Mataray J-M. & Ó.Kovács L. (1997): Chemical Geology 140(1-2), 89–106.

TRACE ELEMENT ANALYSIS OF ORE MINERALS FROM THE BÖRZSÖNY MOUNTAIN

Judit Turi[1,2]* & Viktor Bertrandsson Erlandsson[3]
[1] Supervisory Authority for Regulatory Affairs, Unit of Geology and Laboratory, Budapest, Hungary
[2] Eötvös Loránd University, Department of Mineralogy, Budapest, Hungary
[3] Montanuniversität Leoben, Chair of Geology and Economic Geology, Leoben, Austria
* E-mail: judit.turi@sztfh.hu

Trace elements are key tools for understanding ore forming systems, characterising the different processes leading to ore formation and uncovering fluid evolution. These elements are suitable to trace the origin of ore minerals, furthermore, trace element distribution can help in distinguishing different types of ore deposits.

Based on former investigations, mineralizations of the Börzsöny mountain represent different parts of a porphyry copper system, although we have only indirect evidence regarding the existence of a porphyry body as there were no drills reaching the intrusion. Geophysical measurements and endomagmatic rock inclusions suggest the presence of a large dioritic intrusive body at a depth of about 2.5 km from the surface (Csillagné Teplánszky et. al., 1983). Three deposit types were determined in this area: 1) Low-sulphidation type epithermal veins, located in the central part of the Börzsöny, 2) Metasomatic Pb-Zn(-Ag-Au), located below the epithermal veins and in the upper level of the southern mineralized area, 3) „Weak" porphyry copper mineralization, located in the deep level of the central and the southern mineralized area (Pentelényi & Vetőné, 1996).

Main ore mineralizations of the central, epithermal part consist of the association of sphalerite-galena-pyrite and arsenopyrite-pyrrhotite-pyrite-sphalerite-chalcopyrite-galena-native bismuth-bismuthinite-native gold. These assemblages are accompanied by carbonates (calcite, siderite), clay minerals (illite, kaolinite), quartz and in some cases chlorite. In a low-sulphidation epithermal system, low-moderate ore forming temperature (<250°C) and low salinity (1-2 wt% NaCl eq.) could be expected because of the long term fluid-rock interaction and mixing of the hydrothermal fluids with meteoric water (Sillitoe & Hedenquist, 2003). In contrast, fluid inclusion studies of Gatter (1980) (in Dódony, 1990) and Dódony (1990) mention higher temperatures (290-325°C and 340-355°C) and hipersaline liquid (28,5-29,5 wt% NaCl eq.) as well.

In this research, we measured the trace element composition of sphalerite, chalcopyrite, pyrrhotite, pyrite and marcasite from the epithermal mineralizations with LA-ICP-MS, in order to reach better understandig in fluid evolution of the ore forming system and clarify the mentioned contradictions. In case of the sphalerite, trace element distribution was investigated as well with trace element mapping. Our results with the application of GGIMF sphalerite thermometer (> 300°C) (Frenzel et al., 2016) and Se pyrite thermometer (in some samples > 400°C) (Keith et al., 2018) are consistent with this high temperature suggested by fluid inclusion microthermometry. In addition, high Sn content of some sphalerite (1000-4000 ppm) and chalcopyrite (700-1000 ppm) may reflect the effect of lower-crust assimilation during the evolution of magmatic rocks of the first stage of the middle-miocene volcanism in the Börzsöny (Harangi et al., 2001).

Regarding the above contradictions and new findings the earlier genetic models might be revisited.

References

Csillagné Teplánszky E., Csongrádi J., Korpás L., Pentelényi L. & Vetőné Ákos É. (1983): Annual Report of the Hungarian Geological Institute of 1981, 77–127.

Dódony I. (1990): Research report, Eötvös Loránd University, Department of Mineralogy, Hungarian National Geological, Geophysical and Mining Data Repository, T.16884

Frenzel M., Hirsch T. & Gutzmer J. (2016): Ore Geology Reviews, 76, 52–58.

Harangi Sz., Downes H., Kósa L., Szabó Cs., Thirlwall M. F., Mason P. R. D. & Mattey D. (2001): Journal of Petrology, 42, 1813–1843.

Keith M., Smith D. J., Jenkin G. R. T., Holwell D. A. & Dye M. D. (2018): Ore Geology Reviews, 96, 269–282.

Pentelényi L. & Vetőné Ákos É. (1996): Research report, Hungarian Geological Institute, Hungarian National Geological, Geophysical and Mining Data Repository, T.17637.

Sillitoe R. H. & Hedenquist J. W. (2003): SEG Special Publication 10, 315–343.

DIFFERENTIATION AND CRUST FORMATION ON THE UREILITE PARENT BODY

Zoltan Vaci[1]*, Daniel Sheikh[2], Vinciane Debaille[3], Geneviève Hublet[3], Jerome Gattacceca[4], David Au Yang[4], & Ansgar Greshake[5]

[1] Charles University, Institute of Petrology and Structural Geology, Prague, Czech Republic
[2] Portland State University, Department of Geology, Cascadia Meteorite Laboratory, Portland, USA
[3] Université Libre de Bruxelles, Laboratoire G-Time, Brussels, Belgium
[4] Aix-Marseille University, CNRS, IRD, INRAE, CEREGE, Aix-en-Provence, France
[5] Museum für Naturkunde, Berlin, Germany
* E-mail: zoltanv@natur.cuni.cz

Ureilites are primarily ultramafic rocks which constitute the second largest group of achondrites by number of recovered samples after the HED (howardite, eucrite, diogenite). Ureilites are classified as primitive achondrites, suggesting that the ureilite parent body (UPB) experienced low degrees of melting and differentiation without planetesimal meltdown or the formation of a magma ocean (e.g., Warren, 2012). This is in contrast to the HED parent body, which either experienced a magma ocean or incremental melting, resulting in metallic core formation and a petrologic sequence ranging from olivine-rich cumulate rocks to basaltic crustal material (Mittlefehldt, 2015). Instead, ureilites are coarse-grained restites composed of olivine, pyroxene, and graphite that show large degrees of geochemical and isotopic variability. Thus the nebular precursor material that formed the building blocks of the UPB was never homogenized as it was in planets and planetesimals that melted completely, and ureilites are remnants of a catastrophically disrupted planetesimal mantle (Sanders & Scott, 2017).

Recent meteorite finds have demonstrated that ureilite mantle material has a complementary crustal component. Earlier studies of polymict ureilites suggested that the UPB had undergone low degrees of partial melting, resulting in plagioclase-bearing clasts with typical magmatic compositional variability (Kita et al., 2004). More recently, the trachyandesite ALM-A was found among the primarily ureilitic fall Almahata Sitta, confirming that evolved volcanism and crust formation were present on the UPB (Bischoff et al., 2014). Additional finds consist of the diorites Northwest Africa (NWA) 6698 and the newly discovered NWA 16789, which are extremely similar petrologically and geochemically. Both of these meteorites show cumulate morphology and are composed primarily of andesine plagioclase.

NWA 16789 is a newly discovered meteorite that is similar to NWA 6698, ALM-A, and the ureilites overall. NWA 16789 is composed of zoned albitic to andesine plagioclase (75 modal%), paired pigeonite and augite (21 modal%), microlitic interstitial glass (3 modal%), and minor chromite, ilmenite, troilite, and merrillite. It also contains a cm-sized albite megacryst that hosts melt inclusions with compositions identical to that of the interstitial glass. Geochemically, NWA 16789 is enriched in incompatible elements, with 11-12× chondritic rare earth element (REE) abundances but without the slight positive Eu anomaly observed in ALM-A or NWA 6698.

The oxygen isotopic composition of NWA 16789 plots near the heavy end of the ureilite field along with ALM-A, NWA 6698, and the felsic clasts found in polymict ureilites. However, NWA 16789 displays the heaviest O isotopic composition observed so far for an achondrite associated with the UPB. Al-Mg age dating reveals an age of 4563.89 ± 1.49 Ma when using the CAI age of 4568.22 ± 0.17 Ma as an anchor, or 4564.16 ± 0.37 Ma when using the d'Orbigny angrite age of 4563.37 ± 0.25 Ma as an anchor. Both of these ages are at odds with the age of CAI + 6.5 Ma determined for ALM-A by Bischoff et al. (2014), suggesting either that their age is wrong or that these two meteorites were formed by magmatic episodes separated by at least 3 Ma. In our view this is unrealistic, given the recent Mn-Cr chronology that suggests the UPB underwent secondary reduction due to catastrophic destruction by CAI + ~4 Ma (Kruttasch et al., 2024).

References

Warren P. (2012): Meteoritics & Planetary Science, 47(2), 209–227.

Mittlefehldt D. (2015): Chemie der Erde, 75, 155-183.

Sanders I., Scott E., & Delaney J. (2017): Meteoritics & Planetary Science, 52(4), 690–708.

Kita N., Ikeda Y., Togashi S., Liu Y., Morishita Y. & Weisberg M. (2004): Geochimica et Cosmochimica Acta, 68(20), 4213–4235.

Bischoff A., Horstmann M., Barrat J.A., Chaussidon M., Pack A., Herwartz D., Ward D., Vollmer C. & Decker S. (2014): PNAS, 111(35), 12689–12692.

Kruttasch P., Anand A., Warren P., Ma C. & Mezger K. (2024): Geochimica et Cosmochimica Acta, 383, 108–119.

Goodrich C., Scott E. & Fioretti A. (2004): Chemie der Erde, 64, 283–327.

JEOL EPMA AND SXES, TOOLS AND TECHNIQUES

Laurent Vasse*
JEOL (EUROPE) SAS
* E-mail: vasse@jeol.fr

JEOL developed over the past decades a strong experience on EPMA and WDS techniques, we will describe the actual technologies available on your microprobe, in order to support your analysis among several techniques. SXES has been developed initially for a Transmission Electron Microscope by Prof. Terauchi at Tohoku University (2005-2007) and the goal was to reach 0.2 eV energy resolution @Al-L emission. Thanks to those developments and patents, we can offer to the community a technique suitable for vacuum range of 10-5 Pa in order to get the chemical bonding analysis with a strong limit detection of 20ppm on Boron.

REOCCURRING CRYSTAL PATTERNS OF THE TARANAKI TRANSCRUSTAL MAGMATIC SYSTEM (65-34KA), NEW ZEALAND

Aliz Zemeny[1]*, Georg Florian Zellmer[2], Teresa Ubide[3], John Caulfield[3] & Jonathan Procter[4]
[1] European Space Agency, European Research and Technologies Centre, Noordwijk, the Netherlands
[2] University of Bonn, Institute of Geosciences, Germany
[3] The University of Queensland, School of Earth and Environmental Sciences, Brisbane, Australia
[4] Massey University, School of Agriculture and Environment, Palmerston North, New Zealand
* E-mail: a.zemeny@gmail.com

This study presents a comprehensive mineral chemistry investigation of the vesicular pyroclastic products from the 65-34ka eruptive units of Taranaki Volcano, New Zealand (Zemeny et al., 2021). The pyroclasts are microcrystalline with moderate vesicularity and variable crystallinity (25–65 vol.%), and they contain a mineral assemblage dominated by plagioclase (45–76 vol.%), clinopyroxene (19–37%), amphibole (1–25%), and Fe-Ti oxides (2–5%), with minor occurrences of orthopyroxene and olivine (Zemeny et. al., 2023).

Plagioclase macrocrysts (300 µm to 3 mm) exhibit complex textures and zoning patterns, with compositions ranging from An_{13} to An_{91}. Crystals commonly display patchy cores, multiple mantles, and oscillatory or reverse-zoned rims. Patchy zoning is the most prevalent (77.5%), often accompanied by melt blebs and micro-inclusions of pyroxene and oxides. More than 80% of the analysed plagioclase crystals exhibit multiple types of zoning, most commonly combinations of patchy, oscillatory, and reverse zoning. Resorption textures are widespread, involving cores, mantles, and rims, and are expressed through amoeboid interfaces and dissolution surfaces. While 52% of the crystals exhibit a single resorption event, 40% show multiple resorption surfaces. Anorthite contents generally decrease from cores ($An_{50–90}$) toward mantles and rims ($An_{35–70}$), with GP2 and GP3 showing greater compositional variability than GP1. Trace element mapping reveals that rims and mantles are enriched in Li, Ba, Sr, and Ce, with patterns of oscillatory and rim-specific enrichment common. Some crystals also show Sr-rich mantles and rare sector zonation in trace elements.

Clinopyroxenes (200 µm to 1 mm) from all three units display complex major and trace element zoning, with core-mantle-rim compositions ranging from $Wo_{25–50}En_{16–51}Fs_{10–46}$ and Mg# values from 0.50 to 0.74. Zoned textures include patchy, oscillatory, and sector zoning, along with resorption surfaces. Oscillatory zoning is most common (50%), often associated with multiple zoning types within a single crystal. Mg# values vary significantly within crystals (ΔMg# = 0.03–0.2), independent of crystal size or unit. Trace element patterns include Cr-, Ni-, and Sc-rich cores and mantles, as well as rims enriched in mildly incompatible elements (Zr, La, Nd, Ti). Over 55% of pyroxenes show no resorption, while 30% exhibit at least one resorption surface.

Fe-Ti oxides, primarily titanomagnetite, occur as microphenocrysts and glomerocrystic aggregates with pyroxene ± plagioclase. TiO_2 contents range from 5.74 to 10.04 wt.%, and MgO from 1.5 to 4 wt.%, with GP3 titanomagnetites exhibiting compositions that correlate well with whole-rock data. GP1 titanomagnetites have the lowest TiO_2 contents, while GP2 contains the highest.

Amphiboles (1–25%) are classified as Ti-rich pargasites. Two types were identified: (i) flat or patchy crystals without decompression rims and (ii) flat crystals with decompression rims (~100 µm thick), indicative of rapid ascent and pressure drop during eruption onset. Amphiboles have Mg# values of 0.54–0.56 and Al_2O_3 contents between 10.9 and 11.7 wt.%.

Overall, the mineral textures and chemical zoning patterns indicate a complex, open-system magmatic history marked by repeated magma recharge, mixing, and crystallization under variable pressure-temperature conditions. This study contributes to a refined understanding of magmatic processes beneath Taranaki Volcano and provides a foundation of integrated textural and geochemical data for future research.

References

Zemeny, A., Procter, J., Németh, K., Zellmer, G.F., Zernack, A.V. & Cronin, S.J. (2021): Sedimentology, 68(6), 2422–2449.

Zemeny, A., Zellmer, G.F., Ubide, T., Smith, I.E.M., Procter, J., Tapu, A.T., & Zernack, A.V. (2023): Journal of Petrology, 64(5), egad027

We thank our partners for making the conference possible with their financial support!

Auro-Science Consulting Ltd., Flextra-Lab Ltd., JEOL Europe SAS, Logitech Ltd.,
Stuers GmbH, UNICAM Hungary Ltd., Vacuum Service Ltd.