CETEG25

21st Meeting of the Central European Tectonic Studies Groups

23–26 April, 2025

Nové Hamry, Czech Republic

Warning: Attending this conference may result in increased knowledge, unexpected networking, and excessive coffee consumption.

Contents

About

CETEG25

Mission

The mission of the Central European Tectonic Groups (CETEG) is to strengthen the professional communication and the coordination of activities of formal groups and individuals from the Central European countries interested in broadly scoped tectonics and geodynamics of the Earth crust. According to the assumed convention, scientific gatherings of CETEG are to be held annually in geologically attractive regions, each year in the different member country. The Central European Tectonic Group is an open scientific association bringing together the geoscientists with the interest in geodynamics of the Earth crust in a broad measure. The already well-established topics of the annual meetings are related to the structural evolution of the orogenic belts, basin evolution, a relationship of magmatism and tectonics and other subjects, studied by the methods of structural geology, petrology, geochemistry, sedimentology and geophysics.

CETEG 2025

The CETEG 2025 meeting is organized by:

- Institute of Petrology and Structural Geology
- Czech Geological Survey

in cooperation with Institute of Rock Structure and Mechanics of the Czech Academy of Sciences.

Organizing committee

- Ondrej Lexa (Faculty of Science, Charles University)
- Petr Jeřábek (Faculty of Science, Charles University)
- Pavlína Hasalová (Czech Geological Survey)
- Daniela Třebínová (Czech Geological Survey)
- Anna Velímková (Czech Geological Survey)

Agenda

Pre-conference trip - 23 April, Wednesday

7:30–8:00 Breakfast

8:00 Bus departure

18:00 Estimated arrival to Nové Hamry

19:00 Ice-breaker party

Conference day I. - 24 April, Thursday

7:30–8:50 Breakfast

8:50–19:00 Scientific program

19:15 Dinner

Conference day II. - 25 April, Friday

7:30–8:50 Breakfast

9:00–17:00 Scientific program

19:30 Awards

20:00 Gala dinner

21:00 Live music - Pohřební kapela

Post-conference trip - 26 April, Saturday

7:30–8:30 Breakfast

8:30 Bus departure

16:00 Estimated arrival to Nové Hamry

Registration and information desk

The registration and information desk will be open on 23rd April from 17:00–20:00 and on 24th April from 8:15–8:50.

Enquiry

Email: daniela.trebinova@geology.cz, anna.velimkova@geology.cz

Website: https://echelon.natur.cuni.cz/ceteg

Timetable

24 April 2025, Thursday morning

7:30–8:50 Breakfast

8:50–9:00 Welcome remarks

Session 1	Seismicity and Tectonic Instability | Chair: Dušan Plašienka
9:00–9:18	**Kamil Ustaszewski** (*University Jena, Germany*) – Dating prehistoric seismicity in the Alps using trapped charge methods on incohesive fault rocks
9:18–9:36	**Petra Štěpančíková** (*IRSM CAS, Prague*) – Late Quaternary activity of Mariánské Lázně fault and its complexity (Cheb Basin, Bohemian Massif)
9:36–9:54	**Thanh Tung Nguyen** (*NCU, Taiwan*) – Tectonic Instability in a Supposedly Stable Region: Paleo-Landslides as Evidence of Past Seismicity
9:54–10:12	**Mohamed Abdelkader** (*University of Debrecen, Hungary*) – Assessing Rockfall Hazards: Integrating Geological Structure Analysis and RockFall Simulation for Risk Mitigation
10:12–10:30	**Miklos Kazmer** (*Eötvös University, Hungary*) – Medieval earthquakes at the western margin of the Bohemian Massif (Czechia) – archaeological and historical evidence

10:30–11:00 Coffee break

Session 2	Tectonics and Orogeny | Chair: Kamil Ustaszewski
11:00–11:18	**Karel Schulmann** (*Czech Geological Survey, Prague*) – Variscan orogeny: a three oceans problem
11:18–11:36	**Stanisław Mazur** (*IGS PAN, Poland*) – German-Polish Caledonides and their connection with the Thor suture
11:36–11:54	**Ralf Schuster** (*GeoSphere Austria, Vienna*) – Tectonostratigraphy of the southeastern part of the Bohemian Massif
11:54–12:12	**Dušan Plašienka** (*CU Bratislava, Slovakia*) – The Western Carpathians: a polycyclic Meso-Cenozoic orogen
12:12–12:30	**Martin Keseberg** (*TU Bergakademie Freiberg, Germany*) – Tectonic Architecture of the Erzgebirge/Krušné Hory

12:45–14:00 Lunch

24 April 2025, Thursday afternoon

Session 3	Magmatism and Petrology | Chair: Ralf Schuster
14:00–14:18	**Vojtěch Janoušek** (*Czech Geological Survey, Prague*) – Age, variability and origin of the gabbros–granodiorites in the Nasavrky Plutonic Complex (Železné Hory Mts, Bohemian Massif)
14:18–14:36	**Máté Szemerédi** (*University of Szeged, Hungary*) – Variscan S-type granitoids in the Tisza Mega-unit: petrology, zircon U-Pb dating, and correlations
14:36–14:54	**Štěpán Dvořák** (*Charles University, Prague*) – Continental late-rift volcanic activity from a geochemical, petrological and tectonic perspective (Tosa Sucha Volcanic Complex; Southern Main Ethiopian Rift)
14:54–15:12	**Milan Kohút** (*Slovak Academy of Sciences, Bratislava*) – The Staré mesto granite – an older granite in the Malé Karpaty Mts. (Tatric unit, Western Carpathians)
15:12–15:30	**Igor Broska** (*Slovak Academy of Sciences, Bratislava*) – Records of Cadomian/Cenerian sources in the Variscan-related granitic rocks of the Western Carpathians: Data from geochemistry and geochronology

15:30–16:00 Coffee break

Session 4	Metamorphic Processes and Zircon Geochronology | Chair: Thorsten Nagel
16:00–16:18	**Pavla Štípská** (*Czech Geological Survey, Prague*) – Melt-mediated coupled dissolution-precipitation (MM-CDP) of zircon - a new mechanism of zircon modification in metagranite
16:18–16:36	**Jaroslaw Majka** (*Uppsala University, Sweden*) – Late Neoproterozoic metamorphism in Svalbard: anomalous entity or an effect of a larger scale orogenic event?
16:36–16:54	**Martin Racek** (*IPSG, Charles University, Prague*) – Stability of jadeite in UHP metamorphosed felsic rocks, example from the Bohemian Massif
16:54–17:12	**Petra Holá** (*Czech Geological Survey, Prague*) – Zircon in different textural positions as an important indicator for multi-stage evolution of metagabbroic rocks: insights from the Teplá-Barrandian Unit, Bohemian Massif
17:12–17:30	**Tereza Zelinková** (*Czech Geological Survey, Prague*) – Petrological and geochemical assessment of the formation of mafic–intermediate pyroxene granulites at the contact between Ky-bearing felsic granulites and garnet clinopyroxenites (Dunkelsteiner Wald, Gföhl Unit in Lower Austria)
17:30–19:00	**Poster session**

19:15 Dinner

25 April 2025, Friday morning

7:30–8:50 Breakfast

Session 5	Cratonic evolution and detrital geochronology | Chair: Stanisław Mazur
9:00–9:18	**Lenka Baratoux** (*IRD Toulouse, France*) – Geodynamic processes in the Archean - Paleoproterozoic collisional zone in the West African Craton (Côte d'Ivoire)
9:18–9:36	**Robyn MacRoberts** (*University of Johannesburg, South Africa*) – Were the Kalahari and Congo cratons adjacent or apart in the Rodinia Supercontinent? A U-Pb detrital zircon investigation of the Central Zone of the Damara Belt, Namibia
9:36–9:54	**Ludwik de Doliwa Zielinski** (*AGH University of Krakow, Poland*) – Tracing Alpine Tethys subduction in the Western Carpathians: U-Pb Geochronology of detrital rutile
9:54–10:12	**Stephen Collett** (*Czech Geological Survey, Prague*) – Distal versus local sources in the Devonian of Brunia
10:12–10:30	**Sanja Šuica** (*Univeristy of Zagreb, Croatia*) – Provenance of siliciclastic detritus from Cretaceous synorogenic basins in the NW Dinarides based on zircon U-Pb ages

10:30–11:00 Coffee break

Session 6	Structural Geology and Resources | Chair: Lenka Baratoux
11:00–11:18	**Rastislav Vojtko** (*Comenius University Bratislava, Bratislava*) – Structural control on the epithermal Au-Ag-Pb-Zn-Cu deposit at Banská Hodruša (Štiavnica Stratovolcano, Western Carpathians)
11:18–11:36	**Mohammed Noor Hassan** (*University of Debrecen, HUngary*) – Tectonic Fracture Analysis, Remote sensing, GIS, and Geophysical Characterization for Groundwater Exploration in the Red Sea Hills, Sudan
11:36–11:54	**Rostislav Melichar** (*Masaryk University, Brno*) – Mind versus nature: psychological traps in structural geological research and their reflection in geological maps
11:54–12:12	**Piotr Strzelecki** (*AGH University of Krakow, Poland*) – Tracing faults: From LiDAR pixels to outcrops – resolving the structural complexity of the Bystre thrust-sheet (Outer Carpathians, Poland)
12:12–12:30	**Aleksander Kowalski** (*PGI NRI Wrocław, Poland*) – What to do, when you "see nothing" in the field? Case of the Glinno Graben on top of the Góry Sowie Massif (the Sudetes, NE Bohemian Massif, SW Poland)

12:45–14:00 Lunch

25 April 2025, Friday afternoon

Session 7	Geological Methodologies and Challenges | Chair: Lucie Tajčmanová
14:00–14:18	**Petra Maierová** (*Czech Geological Survey, Prague*) – Numerical simulations of subduction, relamination and accretion of magmatic arcs
14:18–14:36	**Václav Špillar** (*IPSG, Charles University, Prague*) – Self-limited nature of interstitial convection in crystal mushes as a novel mechanism of melt differentiation and cumulate formation
14:36–14:54	**Dominika Linzerová** (*IPSG, Charles University, Prague*) – Disequilibrium enhanced equilibration: Dynamics and textural evolution of cumulate interface
14:54–15:12	**Zhi Zhang** (*Czech Geological Survey, Prague*) – Formation of Miocene ultrapotassic rocks in the Lhasa Terrane, Tibetan Plateau: A relamination mechanism
15:15–17:00	**Poster session**

19:30	Awards
20:00	Gala dinner
21:00	Live music - Pohřební kapela

Posters

1	**George Joel Agyemfra** – Evolution of the Kumasi Basin and the Impact of Alluvial Mining
2	**Paweł Aleksandrowski** – Upper lithosphere structure of the East European Craton based on 660 km-long, SW-NE-directed seismic profile SHIELD'21 across Ukraine from the Carpathians to Dnieper-Donets Basin
3	**Jakub Andrzejak, Konrad Lukaj** – Impact of the tectonic framework on arsenic occurrence in water from the Bystre Thrust-Sheet (Outer Carpathians, Poland)
4	**Abazar M. A. Daoud** – The Influence of joints and bedding planes on the slope stability: Case studies from highly fractured basement terrains and sandstone sedimentary rocks
5	**Luc Louis André de Hoÿm de Marien** – Sequential replacement of Ti-bearing minerals in a Variscan granulite discriminate several stages during the exhumation of a high-pressure eclogite-bearing unit of the Massif Central (France)
6	**Václav Dušek** – Anisotropy of magnetic susceptibility (AMS) as a tool for analyzing landslide deposits
7	**Shah Wali Faryad** – Textural justification for the origin of multiphase inclusions in garnet from eclogite facies rocks
8	**László Fodor** – Migration of deformation, basin subsidence, magmatism in the extensional Pannonian Basin: good fit between numerical models and observations
9	**Simon Fuhrmann** – Deformation at the base of the Bergell Pluton in the upper Valle dei Ratti (Italy) – Observations and regional speculations
10	**Alexandra Guy** – Potential field and metamorphic study of the northeastern part of the Moldanubian domain
11	**Tadeáš Hájek** – Petrogenesis, fabric pattern and emplacement of the Weinsberg Composite Pluton (Moldanubian Batholith)
12	**Pavel Hanžl** – Carboniferous to Early Permian volcanism in the area of Khar Aadzragyn Nuruu, Mongolian Altai
13	**Pavlína Hasalová** – Hybridization of magmas by break down of partially molten granitic rock and its assimilation
14	**Gábor Héja** – Soft-sediment deformation in the Late Triassic – Early Jurassic Csővár Basin, Hungary – implications for platform to basin transition geometry
15	**Ervin Hrabovszki** – Petrography of tectonic veins in a Middle Permian–Early Triassic sequence, SW Hungary
16	**Tamara Ildžová** – Metamorphic record of subduction in metapelites of the Saxothuringian orogenic wedge
17	**Jan Juráček** – Tectonics of the Polička Fault – preliminary results (Czechia)
18	**Klára Jůzlová** – The metasediments of the Zábřeh Crystalline Unit
19	**Radek Kolačný** – Seismic and Field Traces of the Holešov and the Kroměříž faults
20	**Ondřej Krýza** – Influence of caprock on extrusion style and shallow deformation of salt diapirs
21	**Karolina Kucharz** – GeoTwin: Digital twin of the Bieszczady Mountains – Project concept

22	**Jan Kulhánek** – Experimental synthesis of garnet reference materials for in situ lithium isotope analysis in subduction zone garnets
23	**Aurélien Lechner** – Geophysical and structural study of the Permian Uranium mineralization in the north-eastern part of the Třebíč Massif
24	**Gyula Maros** – From a new conceptual geotectonic model to a geothermal management system: the Budapest Thermal Karst
25	**Richard William McIntosh** – The relationship between rock mass strength and geomorphology in the Bükk Mts, Hungary
26	**Tongasoa Miha** – Tectonometamorphic evolution of (U)HT domains in southern Madagascar
27	**Mateusz Mikołajczak** – Deep structure of the Western Carpathians in southeastern Poland: New insights from integrated geophysical and well data
28	**Ahmed S. Ali Mohamed** – Employing seismic interpretation for targeting some reservoirs at the Main Abu El-Gharadig oil field, North Western Desert, Egypt by utilizing velocity, inversion models and structural analysis
29	**Marína Molčan Matejová** – Radiolarians and monazites: reflection of specific conditions during the mélange formation and exhumation of the Meliata Unit
30	**Alexandra Molnárová** – Alpine zircon in the Variscan granitoid intrusion (Veporic Unit, Western Carpathians, Slovakia): record from close Alpine intrusive overprint?
31	**Thorsten Nagel** – Vertical extrusion of subducted continental crust: A modeling study for the Rhodope metamorphic complex
32	**Małgorzata Nowak** – First U-Pb dating of UHP garnet from coesite-bearing eclogites from the Śnieżnik Massif (NE Bohemian Massif)
33	**Petar Pongrac** – Influence of grain size on quartz deformation in pure and general shear experimental setups
34	**Iva Olić Peco** – Exhumation of the western part of the Sava suture zone: Insights from Zrinska Gora (Croatia)
35	**Pavel Pitra** – Isothermal compression of an eclogite from the Western Gneiss Region (Norway)
36	**Tomáš Potočný** – The specific crystallographic and microstructural aspects of coesite to quartz phase transition during the initial stage of UHP rocks recrystallization (Dora Maira, Western Alps)
37	**Aya S. Shereif** – Integrated remote sensing and geophysical approaches for delineating structural controls on radioactive mineralizations: A case study from the Central Eastern Desert, Egypt
38	**Rafał Sikora** – Tectonic and geomorphological conditions of small lakes development at the southern margin of the Arts Bogd massif (Govi Altai Range, Mongolia)
39	**Igor Soejono** – Ancient magmatic basement of the Bohemian Massif as a possible paleogeographic tracer
40	**Jérémie Sodlner** – New petrochronological and metamorphic constraints on the early Paleozoic tectono-thermal evolution of the Alashan block (NW China)
41	**Tanishka Soni** – Deep crustal structure of the tectonic contact between Europe and ALCAPA in the Western Carpathians revealed by Receiver Function analysis

42	**Alessia Tagliaferri** – Alpine garnets under pressure: exploring chemical and mechanical modifications in Dora Maira whiteschists
43	**Martin Tecl** – Pressure-temperature history of eclogite facies rocks with reaction overstepping during metamorphism
44	**Tichomirowa Marion** – Diachronous pulses of Variscan magmatic activity in the Eastern and Western Erzgebirge (Germany and Czech Republic), their relation to ore formation and exhumation history
45	**Okayo Toure** – Preliminary elaboration of a 3D crustal model of the Moldanubian and the Bruno-Vistulian domains, southeastern part of the Bohemian Massif
46	**Lucie Uhrová** – Ordovician metasyenite from the Bíteš Group – an exceptional indication of the Early Palaeozoic extension inside the Brunovistulian domain
47	**Zoltán Váci** – Pyroxene growth kinetics in basalt and andesite as a function of undercooling
48	**Anna Vávrová** – Microstructural evolution of pencil gneiss of the Kouřim unit
49	**Kryštof Verner** – The National Geological and Hydrogeological Map of Ethiopia
50	**Pedro Vila de la Huerta** – Melt-assisted zircon modification leads to challenges in age interpretation, the South Bohemian granulite massifs
51	**Rastislav Vojtko** – Alpine tectonic evolution of the Tatra Mountains (Western Carpathians) inferred from structural, sedimentary and fission track data
52	**Alice Wantz** – Grain-scale melt percolation in the crustal-scale shear zones in southern Madagascar
53	**Prokop Závada** – U-Pb and Hf isotope record in zircon of the Gföhl orthogneiss

Assessing Rockfall Hazards: Integrating Geological Structure Analysis and Rock-Fall Simulation for Risk Mitigation

S ***Mohamed M. Abdelkader***[1,2*], ***Árpád Csámer***[1,3]
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Rockfalls represent one of the major natural hazards globally, especially in mountainous areas, and cause heavy damage and loss of life. These risks are especially dangerous due to their unpredictability and varying magnitudes. In the developing countries, urbanization and insufficient infrastructure enhance the susceptibility to rockfall hazards. This research examines the stability of rock slopes in the northern Gebel El-Mokattam area in Cairo, Egypt. Field observations show that the area is characterized by a complex geological structure, with predominant normal faulting. The faults are mainly related to the formation of extensive joint systems and tension cracks within the Middle and Upper Eocene limestone formations. The presence of these structural discontinuities lowers the strength of the rock masses, making them highly susceptible to rockfalls. The rock slopes in that region are characterized by highly fractured medium to weak strength limestone intercalated with highly swelling clays. The intersection of various fault trends, particularly the NW-SE and NE-SW directions, has created a highly fractured rock mass. These fractures act as pathways for water infiltration, which promotes rock weakening and slope failures. To simulate and analyze potential rockfall events, we utilized RockFall software to simulate of rockfall trajectory, kinetic energy, velocity, and rebound heights, hence providing a complete understanding of the dynamics involved in rockfalls. The combination of geological investigations with advanced simulation programs such as RockFall is key to establishing successful risk minimization strategies for rockfall-prone zones. This research emphasizes the need to recognize structural factors influencing slope stability and proves the benefits of simulation modeling for the development of effective protection measures.

Evolution of the Kumasi Basin and the Impact of Alluvial Mining

S ***George Joel Agyemfra*, Péter Rózsa***

Department of Mineralogy and Geology, University of Debrecen, Hungary

The Kumasi Basin, a key structural and metasedimentary feature within Ghana's Paleoproterozoic terrain, has undergone significant geological evolution shaped by tectonic activity, sedimentation, and erosional processes, with recent exploration interest due to its recent discoveries of large-scale economical gold mining potentials. While natural geological forces have historically dictated its development, recent intensive alluvial mining has introduced new variables affecting sediment transport, river morphology, and basin stability. The present study explores the long-term geological evolution of the Kumasi Basin, tracing its formation through structural and depositional changes up to the present day. By integrating geological history with modern remote sensing analyses, this discussion provides a fresh perspective on how both natural and anthropogenic processes continue to shape the Kumasi Basin.

The aim is to initiate conversations between professionals and decision makers on sustainable resource management, sedimentary basin evolution, the effects of intense mining and the role of geospatial technologies in monitoring environmental change.

Moreover, employing remote sensing and GIS techniques highlights recent observations on how alluvial mining is reshaping sediment dynamics, altering drainage networks, and contributing to environmental degradation. Preliminary insights from the current research in mining-affected regions within the basin reveal noticeable topographic changes, increased sediment load in rivers, and shifts in basin hydrology, raising concerns about long-term landscape evolution and sustainability.

Upper lithosphere structure of the East European Craton based on 660 km-long, SW-NE-directed seismic profile SHIELD'21 across Ukraine from the Carpathians to Dnieper-Donets Basin

Paweł Aleksandrowski[1*], Vitaly Starostenko[2], Tomasz Janik[3], Anna Murovskaya[2,4], Wojciech Czuba[3], Piotr Środa[3], Tamara Yegorova[2,4] et al.

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A wide-angle reflection and refraction (WARR) profile SHIELD'21, carried out in 2021, crosses the western, central, and northeastern regions of Ukraine. It targeted the structure of the Earth's crust and uppermost mantle of the southwestern part of the Precambrian East European Craton, between the Carpathian Foredeep and Voronezh Massif, across the Volhyno-Podolian Homocline, Ukrainian Shield and Dnieper-Donets Basin. The profile is an extension of the earlier RomUkrSeis profile in Romania and westernmost Ukraine. The WARR study, using TEXAN and DATA-CUBE short-period seismic stations, provided high-quality seismic sections from 10 shot points. This allowed constructing a ray-tracing P-wave velocity model, supplemented with the V_p/V_s ratio, for the uppermost part of the lithosphere of the Sarmatian segment of the East-European Craton.

The velocity distribution in the crust, below the sedimentary layer, indicates a rather uniform structure, with velocity change from 6.0 km/s near the surface to 6.8 km/s at the crustal base. The entire section shows the lack of a high-velocity lower crust (V_p >6.8 km/s), which presumably is the result of delamination of the primitive mafic lower crustal layer during the evolution of the juvenile continental crust in Archean – Early Proterozoic times. The crustal boundaries pattern in the crystalline upper crust seems to reflect a Paleoproterozoic large-scale extensional detachment system below the SW flank of the future, Devonian-initiated, Dnieper-Donets rift basin. At a larger depth, a 150 km-wide dome of the lower crust with velocities 6.5 – 6.8 km/s in the SW-central segment of the profile, probably represents a enormous Palaeoproterozoic(?) granitoid batholith.

In the southwesternmost part of the profile, where its intersection with the Teisseyre-Tornquist Zone is anticipated, the crystalline crust is exclusively that of low velocity, with Vp values ranging from 6.10 at the basement top to 6.4 km/s at the crustal base, a phenomenon explainable by a number of competing hypotheses. The prominent Moho is strongly undulated and varies in depth between 32 and 50 km. It is underplated by a number of high-velocity lenticular bodies with velocities of 8.36 – 8.40 km/s, contrasting with the background of 8.16 – 8.25 km/s in the adjacent mantle, where several reflectors have been detected at depths of 55 – 75 km.

Impact of the tectonic framework on arsenic occurrence in water from the Bystre Thrust-Sheet (Outer Carpathians, Poland)

S ***Jakub Andrzejak***[*], S ***Konrad Lukaj***[*], ***Urszula Aleksander-Kwaterczak***, ***Anna Świerczewska***
AGH University of Kraków, Poland

The analysis of the surface and groundwater's chemical composition is one of the fundamental geochemical prospecting methods. By determining the presence and concentration levels of specific elements in water, this method enables the identification and delineation of geochemical anomalies in a given area. Element accumulations are often related to tectonic structures, particularly discontinuous, brittle deformation zones, allowing for the assessment of their permeability as well as the spatial extent of their connections and interactions.

The Bystre Thrust-Sheet is a tectonic structure located within the Fore-Dukla Zone, which is the innermost part of the Silesian Nappe. This locality is the only known occurrence of realgar in Poland, associated with low-temperature hydrothermal epigenetic mineralization of Cretaceous and Paleogene rocks. In addition to arsenic mineralization, hydrothermal processes also manifest through the presence of authigenic quartz and cinnabar. The mineralization is closely associated with discontinuous tectonic zones.

As part of this study, 47 water samples were collected from within and around the Bystre Thrust-Sheet and analyzed for arsenic and 19 other elements presence. Arsenic was detected in 20 samples (38.94 ± 88.28, max = 378.72 µg/L), and its spatial distribution allowed for the geochemical anomaly to be strictly confined to the Bystre Thrust-Sheet area. Spatially, arsenic is predominantly found in water occurring near discontinuous tectonic zones. However, the extent of the anomaly is broader than in situ rocks mineralization. The highest arsenic concentrations occur in waters of the HCO_3-Cl-Na hydrogeochemical type, related to deep groundwater ion composition. A partial correlation, with Spearman coefficients ranging from 0.45 to 0.70, occurs between arsenic and elements which are characteristic of more intensely mineralized paleoinfiltration, synsedimentary waters. This suggests that the primary source of arsenic in the water of the Bystre Thrust-Sheet is the leaching of arsenic-enriched mineralized zones at greater depths, indicating the high permeability of the brittle deformation zones which were migration pathways for hydrothermal fluids.

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Geodynamic processes in the Archean - Paleoproterozoic collisional zone in the West African Craton (Côte d'Ivoire)

Lenka Baratoux[1,2], Alain Kouamelan[2], Augustin Yao Koffi[2], Jean-Herve Fossou Kouadio[2], Thomas G. Kone[2], Stevens Amin[2], Clovis Blanchard Gballou[2], Pavel Pitra[3,4], Olivier Vanderhaeghe[1], Lionel Boya[2], Nicolas Thebaud[5], Olivier Bruguier[6], Oscar Laurent[1], Yacouba Coulibaly[2], Mark W. Jessell[5]*
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The Leo-Man Shield forming the southern part of the West African Craton (WAC) is built of an Archean nucleus (3.6 – 2.6 Ga) tectonically adjacent to supposedly juvenile Paleoproterozoic domains (2.35 – 1.9 Ga). However, growing evidence based principally on U-Pb and Lu-Hf isotopic data points to more complex processes of reworking of the Archean terrains and their interaction with newly formed domains. Three major orogenies operated in the WAC: Leonian (3.4 – 3.0 Ga), Liberian (2.9 – 2.4 Ga) and Eburnean (2.3 – 1.9 Ga), the latter being the most extensively documented in the literature. In Archean terrains, the so-called "hot" or "stagnant lid" tectonics, dominated by gravity-driven vertical processes, is responsible for the formation of the prevalent high-grade granito-gneissic domains and there is an overall agreement about the hotter nature of crust-forming processes, different from the present-day tectonics. On the other hand, the discussion remains vivid when it comes to the Paleoproterozoic domains, with the key questions to be answered: When did the plate tectonics start and what was its early nature? What mechanisms led to the assembly of the Archean nucleus and the Paleoproterozoic terrains and what was the role of the pre-existing Archean crust? The transitional zone between the Archean nucleus and Paleoproterozoic domains (APTZ) in the WAC represents an excellent field laboratory to investigate the geodynamic processes that operated during the Eburnean Orogeny reworking the older terrains. The study area covers a ~600 km $\times$ 200 km large zone located in western Côte d'Ivoire. The present synthesis is based on field-based petrological, geochemical, geochronological, isotopic, and (micro)structural data integrated with airborne magnetic surveys, which partially cover the APTZ. A polyphase tectono-metamorphic history starting at ~3.5 Ga comprises three major periods of crustal growth and reworking at ~3.3 – 3.0 Ga, ~2.9 – 2.7 Ga and ~2.1 – 2.0 Ga. The complex spatio-temporal interference is marked by magmatic and metamorphic inheritance, magmatic crustal contamination documented by Sm-Nd and Lu-Hf isotopes, as well as tectonic slices of Archean units occurring within the Paleoproterozoic ones and vice versa. Magmatic, metamorphic and detrital U-Pb zircon and monazite ages suggest that the collision between the Archean nucleus and the Paleoproterozoic domain occurred at the late stages of the Eburnean orogeny at c. 2090 – 2000 Ma, marked by regional upper greenschist- to granulite-facies metamorphism and abundant migmatization. Crustal thickening was achieved by tectonic shortening and crustal-scale folding, which was followed by and concomitant with lateral flow of the thickened partially molten crust accommodated by regional transcurrent shear zones, documenting an interplay between horizontal tectonic forces and gravity-driven flow.

Records of Cadomian/Cenerian sources in the Variscan-related granitic rocks of the Western Carpathians: Data from geochemistry and geochronology

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Source rocks for the Variscan granites in the Western Carpathians can be detected by (1) zircon isotopic age determinations (2) Hf isotopic on dated zircons (3) Nd whole rock analysis.

New age determination from Variscan granites in the Tatric Unit revealed that the zircon concentrates contain except Variscan zircons also relatively common age-related Late Ediacaran / Cambrian zircons preserved as inherited whole grains in range 559 – 527 Ma. Such ages can be attributed to SAC (subduction-accretions complex) which Zurbriggen (2017) defined in the Strona-Ceneri Alp zone as a large source for Paleozoic magmatism in the area. In the Alps SAC setting can be restricted to a time span from 540 to 410 Ma, from sedimentation of the greywackes and pelites until the peraluminous magmatism with culmination at 490 – 440 Ma (the Ordovician period). Thus, the Cenerian SACs in the Alps are limited to a time span of 540 – 400 Ma with an intense phase between 490 – 440 Ma and such ages dominate also in metagranites and orthogneiss of the Western Carpathians. The most typical representative is Králička metagranite defined for the first time as a special granite type by Zoubek et al. (1951).

The Králička Ordovician metagranite with a weighted average age of 459.0 ± 1.2 Ma show very pronounced S-type characteristic and can be taken as a representative of the typical Cenerian magmatism which wide range $\varepsilon Hf_{(i)}$ values from +9.3 to −12.0 indicates that they were formed from mixed sources which can be derived from the Cadomian/Cenerian subduction-accretionary complex (SAC). Its formation age is spread over a range of ca. 80 Ma, indicating precipitation of zircons over a long time period due to expected long overheating of the SAC by mantle magmas. However, geochemistry and preserved some igneous Variscan zircons indicate that the Králička metagranite underwent also Variscan melting.

The typical I- and S-type Variscan granites show similar isotopic characteristics. The highest mafic source component expressed by positive $\varepsilon Nd_{(i)}$ and $\varepsilon Hf_{(i)}$ values (ca. +2 and +4, respectively) was found in the I-type diorite, while its host S-/I-type granodiorite doped with a crustal material has lower $\varepsilon Nd_{(i)}$ = +0.35 and range of $\varepsilon Hf_{(i)}$ zircons like Ordovician Králička metagranite showed. Summarising data isotopic ages determination and isotopes can be concluded that melted sources for the Variscan granitoids of the Western Carpathians were peraluminous orthogneisses of Cadomian / Cenerian induced by hot mafic mantle magmas which has consequences on metallogenetic capacity of granites.

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Continental late-rift volcanic activity from a geochemical, petrological and tectonic perspective (Tosa Sucha Volcanic Complex; Southern Main Ethiopian Rift)

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Tosa Sucha Volcanic Complex (TSVC) represents a late-rift volcanic sequence of the Southern Main Ethiopian Rift. New K-Ar ages indicate that volcanic activity, characterized by basaltic to basaltic trachyandesite lavas and pyroclastic began around ~0.8 – 1.9 Ma. In the later stage (~0.7 – 0.5 Ma) the volcanic activity continued with a heterogeneous magma composition ranging from basaltic to trachytic. The chemical variations in the volcanic sequences of the TSVC can be explained by fractional crystallization with minimal crustal contamination. Mineral chemistry and geochemical modelling suggest that the initial stage of the TSVC evolved primarily at pressures of ~3 to 4 kbar, driven by fractional crystallization of clinopyroxene and olivine ± spinel and magnetite, under moderately hydrous conditions (H_2O = 2 – 3 wt.%). Pressure estimates from these rocks indicate magma storage and crystallization at a depths of ~9 to 15 km.

The analytical data also reveal the subsequent stages of magmatism occurred under a significantly wider range of crystallization pressure conditions, from 1 to 6 kbar. Based on the inferred crystallization depth (~5 to 22 km) of the second magmatic stage, at least two magma reservoirs with different depths are assumed. The trachytic magmas appear to have been derived from a trachybasaltic melt through the fractionation consisting of clinopyroxene, olivine, and apatite. Kaersutite phenocrysts yield temperatures between 988 to 1024 °C and crystallization depths ranging from ~12 to 15 km. In contrast, the magnesio-fluoro-hastingsite in the crystalline groundmass yielded a temperature of ~800 °C and crystallization depth of about 4 km. The variations in compositon of amphibole are associated with system opening and H_2O loss, decreasing from 4 to 1 wt.%. Our findings are consistent with the inferred position and shape of the low-density magma chamber, as supported by gravity modeling. The fabric pattern and paleostress analysis, combined with the K-Ar dating, indicate synchronous volcanic and tectonic activity, with regional extension oriented in ~SE(ESE)–NW(WNW) direction (azimuth 128°).

Distal versus local sources in the Devonian of Brunia

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Brunia represents an enigmatic crustal block in the European Variscides. In common with the adjacent, Cadomian units of the Bohemian Massif, Brunia is built of a late Neoproterozoic arc complex with Ediacaran to early Cambrian cover. However, the limited preservation of early Palaeozoic strata up to the Devonian complicates understanding of its pre-Variscan relationships. Some models suggest a common crustal domain with the Teplá-Barrandian and Moldanubian units of the Bohemian Massif; whereas, others consider Brunia to be a far eastern extension of the Avalonian microcontinent, accreted to Baltica during the early Palaeozoic. Alternatively, others have argued that Brunia has a long-standing connection to Baltica from at least the late Ediacaran onwards.

To explore these problems, we have performed the first systematic study of detrital zircons in Devonian strata that covers the Neoproterozoic basement. Within these data two distinct patterns can be observed. The first pattern (type-1) is recorded only in strata from the northern, Silesian, part of Brunia. The detrital zircon spectra consist of a multi-modal distribution with principal age peaks in the Late Ordovician–Silurian, and throughout the late Paleoproterozoic to early Neoproterozoic. Only a relatively small component of late Neoproterozoic ages is present in these strata. The second (type-2) detrital pattern, which is documented throughout Brunia, is characterised by a near unimodal peak in the late Neoproterozoic, this peak broadly corresponds to the age of locally preserved arc magmatism and the age distribution closely resembles that reported from Ediacaran strata.

The type-1 pattern has broad similarities to detrital zircon datasets from Devonian strata of the South Portuguese Zone in Iberia, the Avalonian terranes in the British Isles and Germany, the Dobrogea region of Romania, and the Istanbul Zone in northwest Turkey. The strong similarity in these data to detrital zircon patterns from Scandinavia indicates that these datasets likely belong to a vast Caledonide fan and confirm an Early Devonian connection of Brunia to Baltica and Avalonia. In contrast, the type-2 pattern indicates dominance of recycling of local sources within Brunia. Hf isotopic data from the Neoproterozoic zircons in these strata give nearly uniform positive values ($\varepsilon Hf_{(t)}$ = +2 to +9). This is dissimilar to the wide range in Hf isotopic data observed in detrital zircon from other Cadomian terranes of Central and Western Europe, but matches that observed in Avalonian strata from Newfoundland, tentatively supporting connections between West Avalonia and Brunia in the Neoproterozoic.

Granulitized eclogite in the Góry Sowie Block: An exotic or in-situ origin

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Eclogite has important petrogenetic significance in the reconstruction of paleo-subduction zones. Their age, and chemical and isotopic composition can provide insight into the type of material entering the subduction channel and enable reconstruction of pre-orogenic architectures. Eclogite are widely distributed in the Bohemian Massif, cropping-out significantly within a northern belt corresponding to the so-called Saxothurignian or Teplá suture zone. These eclogite can be broadly subdivided into two types, those formed early in the Variscan Orogen (c.400 – 370 Ma) that crop-out in the Münchberg, Marianske Lazne and Góry Sowie (GS) blocks and those that formed later (c.360 – 330 Ma) that crop-out in the Erzgebirge complex. Recent data from the former have been used to establish large-scale correlations in the Variscan belt from Iberia to the Bohemian Massif as the so-called Mid-Variscan Allochthon. We expand upon this correlation with a study of granulitized ecloigte from GS.

Samples for this study were collected in-situ from the Piława Górna quarry in the eastern part of GS and from fieldstone piles in the surrounding area. These samples have broad petrographic similarity, with each consisting of three distinct petrographic domains: (1) garnet with an associated Pl + Hbl + Opx ± Bt corona, (2) Cpx + Pl symplectites, and (3) a coarse-grained Hbl + Bt + Pl matrix. These domains are interpreted as relicts of eclogite-facies metamorphism that has been overprinted by a higher-temperature granulite event. Metamorphic conditions, acquired from garnet rim compositions, Zr-in-rutile abundances, and pyroxene-plagioclase-amphibole symplectite point to a common high-pressure (1.1 – 1.4 GPa) and high-temperature (800 – 870 °C) equilibration of the samples in granulite-facies conditions. Locally, the presence of omphacite as inclusion in garnet (only in the fieldstone samples) attest to an earlier eclogite-facies phase reaching maximum pressures of 2.5 GPa. Temperature estimates of 700 – 750 °C for the eclogite-facies event are established from rutile inclusions in garnet.

In spite of their petrographic similarity, the samples have contrasting geochemistry, most notably those from Piława Górna have lower mg# (c. 0.55 vs. 0.70), higher TiO_2 contents (c. 2.5 vs. <1 wt.%) and a moderate enrichment in LREE over HREE (La_N/Yb_N = 1.65 – 2.36) versus a depletion in LREE in the fieldstone samples (La_N/Yb_N = 0.43 – 0.83). In common, both the Piława Górna and fieldstone samples have negative Nb anomalies (Nb/Nb* < 0.70) and depleted Nd isotopic signatures ($\varepsilon Nd_{(500\,Ma)}$ = +5.0 to +9.7). The composition of the Piława Górna samples are consistent with published data from basic rocks of GS and indicative of a continental rift setting. The fieldstone samples are exotic with respect to existing data and have an oceanic arc affinity. Nonetheless, common age of metamorphic zircons in both types of sample (c.390 Ma) and their shared metamorphic conditions preclude a further travelled (glacial?) origin for the fieldstone samples. Moreover, igneous zircons point to a common protolith age of both types with estimated emplacement ages of 500 – 485 Ma. Thus, the chemical differences may be accommodated by an arc/back-arc relationship for the fieldstone and Piława Górna samples, respectively. These data enhance correlations with the nappe stack in NW Iberia, where late Cambrian arc activity and c.390 Ma eclogites are also recognized.

The Influence of joints and bedding planes on the slope stability: Case studies from highly fractured basement terrains and sandstone sedimentary rocks

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The slope stability strongly influences discontinuities in structurally complex terrains, particularly joints and bedding planes. The current study investigates the role of structural anisotropy in slope instability through two case studies: (1) sandstone-dominated sedimentary sequences in northern Sudan, where the bedding planes show potential failure surfaces in both field and lab measurements, and (2) highly fractured basement rocks in the Red Sea Hills northeast of Sudan, where dense joint networks and foliations control slope failures. In basement complex rocks, four types of rock failure were identified including (plane, toppling, wedge, and circular failures). In contrast, in sedimentary sequences, bedding plane orientation significantly affects the likelihood of plane, and toppling failures. Field observations and geomechanical analyses are used to measure rock mass properties. Results indicate higher compressive strength when the load direction is perpendicular ($\beta = 90°$) or parallel ($\beta = 0°$) to bedding planes, and lower values when inclined ($\beta = 45°$). The findings underline the importance of discontinuities in slope stability assessments, particularly in field where anisotropy utilizes primary control on failure mechanisms.

Tracing Alpine Tethys subduction in the Western Carpathians: U-Pb Geochronology of detrital rutile

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The collision between Europe and Alcapa, a segment of Adria, resulted in the formation and erosion of high-pressure metamorphic rocks within the Carpathian and Alpine arcs. To refine our understanding and timing of the closure of the Alpine Tethys Ocean in the Western Carpathians, we conducted U-Pb geochronology on detrital rutile, a mineral typically formed in high pressure rocks, extracted from medium-grained sandstones of the Magura and Silesian Nappes.

Our study is based on the set of twelve samples from a transect in the Magura Nappe, complemented by three reference samples from the Silesian Nappe. Additionally, three samples from the Altengbach-Formation in the Rhenodanubian Flysch of the Greifensteiner Decke were included for comparison. Approximately 200 rutile grains were separated from each sandstone, and about half were selected for dating.

The detrital rutile from the Magura Nappe predominantly exhibits age peaks corresponding to Variscan (c. 400 – 280 Ma) and Alpine (c. 160 – 90 Ma) tectonic events, with the notable exception of the oldest sample. Four distinct Alpine maxima were identified. The dominant peaks appear at 137 – 126 Ma and 115 – 105 Ma in most samples. The youngest age peak (94 – 90 Ma) is found in the Eocene–Oligocene and Late Cretaceous–Paleocene sandstones. An additional Jurassic peak at 193 – 184 Ma is present in those two samples and one Paleocene–Eocene sandstone. The sandstones from the Silesian Nappe exhibit a strong Variscan signature, while only the late Oligocene sample records younger activity yielding peaks at 180 Ma, 95 Ma, and 26 Ma. Rocks from the Altengbach-Formation reveal Alpine peaks only in the two youngest samples, while Variscan ages are consistently recorded across the whole sample set. The widespread distribution of Alpine-age rutile in all but the oldest sandstone implies a sedimentary connection between southern and central Alcapa and deposition north of the hypothesized Oravic (Czorsztyn) continental fragment within the Alpine Tethys. The absence of young Alpine ages in the oldest sandstone (Late Cretaceous a) may indicate a physical barrier to sediment transport or the lack of rutile-bearing rocks at the surface during its deposition.

Overall, the results of this study suggest that the synorogenic deposits of the Outer Western Carpathians contain detritus sourced from previously subducted, exhumed, and imbricated oceanic and continental crustal units. The predominant ~180 – 105 Ma Ma age range likely reflects the closure of the Neotethys Ocean (Meliata branch) and Cretaceous stacking and exhumation of the Veporic and Gemeric megaunits while the youngest peak at 94 – 90 Ma may correspond to the subduction of the Alpine Tethys beneath Alcapa.

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Anisotropy of magnetic susceptibility (AMS) as a tool for analyzing landslide deposits

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Anisotropy of Magnetic Susceptibility (AMS) refers to the preferred orientation of magnetic minerals within rocks and soils, reflecting the influence of past geological processes. This study examines soil samples from landslide deposits.

To date, over 1,000 soil samples have been collected from various recent to subrecent large-scale landslides in Taiwan (e.g., Tsaoling, Yiufengershan, Shaolin) and from regions in the Czech Republic, where various ancient landslides were identified (e.g., Javorníky Mountains, Pálava region).

For the purposes of this study, the analyzed landslide accumulations can be divided into two groups: (1) well-documented sites where the extent of accumulation, spatial distribution of different segments, and triggering mechanisms are known, serving as reference cases for AMS behavior in landslide deposits, and (2) sites with limited information, where AMS was applied to reconstruct the deformation behavior and movement patterns of the landslide masses, as well as the recent alignment within the deposits.

AMS analysis provides valuable insights into the internal structure and deformation patterns of landslide deposits. It has proven useful in identifying depositional structures in areas where multiple landslides have accumulated over time. The method facilitates the delineation of boundaries between distinct events, both within deposits where landslides are stacked on top of each other and along slopes where older accumulations are buried beneath soils subjected to secondary deformation.

AMS measurements often provide a positional interpretation within an individual landslide mass. Along the downslope direction within the landslide mass, near the source area and in the upper part of the accumulation, magnetic lineation tends to be steep and parallel to the movement direction, with subhorizontal magnetic foliation. Further downslope, particularly in lateral zones of the accumulation, magnetic lineation becomes subhorizontal and perpendicular to the movement direction, while magnetic foliation shifts to a subvertical orientation, reflecting lateral spreading of the material.

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Textural justification for the origin of multiphase inclusions in garnet from eclogite facies rocks

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Polyphase inclusions are commonly found in anhydrous minerals, primarily in garnet, but their origin from eclogite-facies rocks minerals remains a subject of controversy. In low- to medium-temperature eclogite-facies rocks, the inclusion phases are mostly similar to those in the matrix. However, in ultrahigh-pressure rocks or those subjected to high-temperature overprinting, the inclusion phases may undergo recrystallisation and can even exhibit negative crystal shapes. Therefore, in addition to originating as former matrix phases, enclosed by a growing grain, they are also interpreted as products of melt entrapment, particularly when they exhibit negative crystal shapes. Although some of these multiphase inclusions consist of quartz and feldspars and have a granitic melt composition, most contain phases that do not support their formation from granitic or other types of melts. The hypothesis that they originate from supercritical fluids or melts has led to laboratory research aimed at reproducing the original fluids or melts from which these multiphase inclusions may have formed. Therefore, petrological data that can verify or refute this assumption are essential for advancing multidisciplinary research on fluid and melt generation in subduction zones.

This contribution focuses on the textural and compositional relationships among multiphase inclusions in garnet from various lithologies subjected to high- to ultrahigh-pressure metamorphism. The data indicate that multiphase inclusions form through in-situ recrystallization of former (hydrous) solid phases enclosed within host minerals. In addition to identifying the original hydrous solids, the study presents evidence of their transformation into high-pressure phases during prograde metamorphism, as well as their modification and decomposition during retrogression or subsequent heating during decompression. Furthermore, it is examined whether the crystallization of garnet with inclusions aligns with bulk-rock fractionation and thermodynamic modeling and whether the compositions of multiphase inclusions correspond to the pressure-temperature conditions of hydrous melts or supercritical fluids, as suggested by experimental data.

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

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Numerical models are essential tools for investigating a variety of Earth phenomena. 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. In the Pannonian Basin system geological data are abundant, the temporal resolution of basin evolution including magmatic events are good and high-resolution numerical models are available.

We used 3D coupled thermo-mechanical and surface processes numerical models (I3ELVIS-FDSPM code) to simulate continental rifting and to shed light on the temporal evolution of the entire rift system. The extensional deformation starts from the western basin margins, from inherited lithospheric weakness zones than migrates or jumps towards the basin centre. This is followed by a second jump of basin formation back-toward, between the first and second generations of basins. This is in good agreement with the ages for the onset of basin subsidence, major boundary faults including low-angle detachments of metamorphic core complexes. This migration is driven and supported by mantle flow and asthenospheric upwelling, eventually affected by thermal relaxation.

The migration of basin formation shows similar migration of magmatic activity. This started with granodioritic–dacitic products around 18.7 Ma along the western basin margin, then jumped to the central basin part around 17.3 – 16.8 Ma and stepped back around 15.3 Ma. Geochemical characteristics indicate increasing mantle component in the melts during continuing extension until ca. 14.4 Ma. The magma generation in the lower crust and mantle is predicted by numerical models. The evolution of basin formation and magmatism between ~14.9 and ~11.5 Ma is marked by the migration from the basin centre toward the eastern margin and is probably due to subduction roll-back, steepening of the slab and its detachment.

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Deformation at the base of the Bergell Pluton in the upper Valle dei Ratti (Italy) – Observations and regional speculations

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The Bergell Pluton (BP) is a calc-alkaline intrusion located in the Italian Alps, north of the Insubrian Line. The intrusion continues into the Southern Steep Belt (SSB), an E-W-striking, north-block-up mylonite zone that affects the pluton and the underlying high-metamorphic nappe pile.

In the upper Valle dei Ratti, a large antiform (VRA) at the base of the BP is exposed, which translates the base of the intrusive rocks and the underlying gneisses into the SSB. We present a new geological map, structural field data, microstructural observations and EBSD data from this area. Petrological mapping reveals an alternating sequence of Bt-rich gneisses and schists adjacent to more leucocratic gneisses below the BP. Metasedimentary and ultramafic rocks have also been observed at the margins to the Bergell magmatites. Previous maps were inconsistent as despite the recognition of the antiform, the two limbs were displayed as being from two fundamentally different tectonic units below the pluton. We traced metasedimentary layers that prove the continuity of a single basement unit. The VRA and associated small-scale folds show E-plunging fold axes and pronounced stretching lineations parallel to fold axes orientations. This stretching lineation is found in the entire area, also further north in the Gruf complex, and is related to top-east shearing. In the study area, it continuously translates into the lineation associated with north-block-up, left-lateral shearing in the SSB. We propose that the mylonitic shear zone of the SSB is folded together with the base of the BP and is thus identical to right-lateral, south-block-up shearing at the northern border of the Gruf complex further north. This scheme would explain the metamorphic gap on the northern and southern side of the Gruf complex and the absence of the SSB east of the BP. It would actually not be in line with the widely accepted concept that the SSB represents a back-thrust. We rather follow interpretations that the SSB represents an originally southward-dipping shear zone with a normal-sense of motion.

Potential field and metamorphic study of the northeastern part of the Moldanubian domain

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The potential field signal is an expression of the petrophysical properties of rocks at depth, which primarily reflect their mineralogical composition. However, the correct geological interpretation of the geophysical fabrics can be complicated by several factors. One such factor is the change in petrophysical properties due to the metamorphic processes knowing that metamorphic rocks constitute a large proportion of continental crust. The depth variation in average density or magnetic susceptibility (up to the Curie depth) depends on the mean mineral composition of metamorphic rock, but it is difficult to estimate due to the heterogeneity, in both bulk rock composition and metamorphic grade, which creates ambiguity in interpreting gravity and magnetic signals. For example, high-grade garnet-bearing metapelite contains denser mineral phases than its garnet-free low-grade equivalent, but a high-grade metapelite can be similarly dense as low-grade metabasite. Similarly, is the development of iron oxides at low-pressure and rather high-temperature indicative of specific P–T window leading to a strong magnetic signal?

The Bohemian Massif has been thoroughly studied from a geological and geophysical perspectives, resulting in an extensive database that can be used to investigate the possible relationship between metamorphic grades and gravity and magnetic anomalies. More specifically, the Svratka Complex and adjacent units constitute almost the entire crustal section and thus, represent an interesting test area due to their variable lithologies and metamorphic grades. Based on data filtering techniques applied to gravity and magnetic data, followed by the implementation of lineament maps, the metamorphic isogrades are compared with the magnetic and gravity anomaly maps. By studying the metamorphic evolution and the P–T conditions associated with the development of iron oxides and the index minerals, resulting in an increase or decrease in density values, we try to determine the geometries of the successive metamorphic series in depth. This preliminary work may contribute to develop an approach and better constrain potential field studies: by reducing the non-unicity of gravity and magnetic interpretation, including better the metamorphic petrological information.

Petrogenesis, fabric pattern and emplacement of the Weinsberg Composite Pluton (Moldanubian Batholith)

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Granitoid plutons are important markers of magmatic processes, providing key information about magma origin, ascent, and emplacement at various levels of the continental crust, as well as tracing the overall geodynamic history of orogenic belts. The abundant Variscan "late-orogenic granitoids" in the high-grade Moldanubian Zone (Bohemian Massif), which form the large Moldanubian Batholith, have recorded various emplacement mechanisms in the context of regional stress fields. By integrating fabric analysis – including anisotropy of magnetic susceptibility, whole-rock geochemistry, petrology, P–T modeling of magma crystallization, and gravity surveys, we interpret the emplacement mechanisms and cooling history of the Weinsberg Composite Pluton (southeastern Moldanubian Batholith). The results have implications for interpreting similar granitoid bodies in other orogenic belts and refining models of magmatic processes in continental crust.

Carboniferous to Early Permian volcanism in the area of Khar Aadzragyn Nuruu, Mongolian Altai

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Mongolian Altai (MA), as a part of the huge belt of Palaeozoic rocks accreted to the Precambrian Central Mongolian Microcontinent, is dominated by the Cambrian to Devonian oceanic- to continental-arc complexes. The Palaeozoic evolution of the MA culminated in the opening of the Permian intracontinental basins, accompanied by a massive production of volcanic rocks. While tectonic slices of the Mississippian turbidite are common in the MA, Carboniferous volcanism is almost unknown. This contrasts with the Trans-Altai Zone to the south, where products of the Carboniferous volcanic arc dominate.

An approximately 60 km long belt of Late Palaeozoic volcanic and volcaniclastic rocks has been distinguished from the sequence previously defined as the Cambrian (Togtokh et al., 1995). This tectonically bound belt is exposed between the Lake Zone to the north and the Tseel Metamorphic Complex to the south in the mountains north of the Tseel soum in the Gobi-Altai district. The volcaniclastic complex covers the Lower Palaeozoic basement and is spatially related to the Permian intracontinental sedimentary rocks. Generally, two Carboniferous to Early Permian suites were distinguished according to zircon geochronology.

The zircon age patterns from the sandstone and tuff to the south are relatively simple with two dominant clusters. The younger cluster covers the age range 380 – 340 Ma; the source of these zircons could be sought in the (nearly) contemporaneous volcanism and/or in the Late Devonian to Mississippian plutons in the Tseel Metamorphic Complex to the S. The older cluster of 530 – 500 Ma corresponds well with the source in the Ikh Mongol Arc System of the Lake Zone. Sandstone from the NW part of the belt contains clastic zircons yielding ages in the range from 350 to 320 Ma, the age span which correlates with the Mississippian plutons common in the MA.

The studied clastic and volcaniclastic rocks are spatially related to the northerly lying lavas, which are classified as calc-alkaline basalt and andesite to dacite. Their geochemical signature is nearly identical to the nearby Upper Carboniferous–Lower Permian basaltic agglomerate described by Hrdličková et al. (2020). Slightly positive $\varepsilon Nd_{(i)}$ values (+3.6 to +3.7) and low two-stage Depleted Mantle Nd model ages (~0.78 Ga) imply a derivation from a geochemically relatively primitive source. Trace-element signatures correspond to the evolution in a continental volcanic arc.

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Hybridization of magmas by break down of partially molten granitic rock and its assimilation

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During orogenic processes, the continental crust experiences significant partial melting. Repeated thermal pulses or fluctuation in fluid content can even cause multiple anatectic events that result in complex intrusion suites. The Vosges Mountains (NE France) reveal two chronologically and geochemically distinct tectono-magmatic events. An early major pulse of Mg–K magmatism was followed, ten millions years later, by a development of a magma-rich detachment zone and intrusion of the anatectic Central Vosges Granite forming a felsic mush zone. This mush zone was characterized by the production of a large amount of anatectic melts that interacted with the older Mg–K granites, surrounding granulites and metasedimentary rocks. We aim to understand how such hybridization processes impact on the crustal rocks rheology, deformation as well as their geochemistry and geochronology. Three different granite varieties were distinguished: (i) the older Mg–K granite end-member that is coarse-grained with a high proportion of feldspar phenocrysts, yielding zircon U–Pb ages of 340 Ma and having a specific geochemical signature; (ii) medium-grained, phenocrysts-poor type that shows advanced brecciation, whereby fine-grained Pl + Kfs + Qtz form discontinuous corridors or even interconnected network surrounding fractured phenocrysts. Its geochemical signature suggests that it represents a hybrid between Mg−K and Central Vosges granites, as confirmed by the presence of both inherited (340 Ma) and younger (330 – 310 Ma) zircon domains; (iii) isotropic, medium-grained granite with geochemical signature typical of the Central Vosges Granite in which younger zircon domains (310 – 320 Ma) dominate over inherited xenocrysts (340 Ma). These three granite varieties represent different stages of magma hybridization by the breakup of the older Mg–K granite solid framework by the invading younger Central Vosges Granite magmas. The interaction between the new melt and previously crystallized granitoids results in a variety of granite textures, fabrics, chemical compositions, isotopic signatures and deformational behavior. In summary, the resulting signature results from a complex interplay between melt transfer and interaction in the mush zone.

Tectonic Fracture Analysis, Remote sensing, GIS, and Geophysical Characterization for Groundwater Exploration in the Red Sea Hills, Sudan

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The northwestern part of the Red Sea Hills, within the Hamisana region of Sudan is characterized by an arid desert climate and suffers from severe water scarcity. Most people living in these regions suffer from lack of water due to the complicated geological structure, which requires high-method analysis to locate invisible aquifers, enhance water extraction, and secure long-term groundwater sustainability.

This study aims to integrate structural analysis with remote sensing techniques to identify the most promising fracture zones for groundwater occurrence in hard rock terrains. Fracture extension and shear fractures in basement terrains are the power key pathways for groundwater movement, directly controlling storage and recharge in arid regions.

Ductile deformation features in the study area were delineated using Landsat imagery and measurements through field observations. Structural analysis was conducted to classify fractures within the hard rock formations according to the force or direction of collision. Stress-strain analysis was applied to differentiate potential open fractures (extensional, tensional, and release fractures) from closed shear fractures. The results of stress and strain analysis indicate that extensional fractures trend northwest-southeast, while release fractures trend northeast-southwest Over time, due to runoff, weathering, and erosion, some of these fractures evolve into wadis, which can serve as significant groundwater storage zones, corresponding to the first collision between the Haya and Gabiét terrains. Additionally, east-west extensional fractures and north-south release fractures were identified linked to the second collision between the Gabgba and Gabiét terrains.

To further investigate groundwater potential, electrical resistivity geophysical methods were employed to determine the depth (ranging from 40 to 60 m), thickness, and lithological variations of both alluvial and basement aquifers. Geographic Information Systems (GIS) and specialized computer programs were utilized to process and visualize the data, enhancing the interpretation of structural and geophysical findings.

These techniques are significant and used extensively to detect the aquifer in basement terrain and to understand groundwater movement and accumulation through classification fracture and direction of lineament analysis.

Soft-sediment deformation in the Late Triassic – Early Jurassic Csővár Basin, Hungary – implications for platform to basin transition geometry

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The Csővár area is in the northeastern part of the Transdanubian Range Unit, which forms the uppermost thick-skinned nappe of the Cretaceous Austroalpine orogeny that was also influenced by Miocene normal faulting related to the formation of the Pannonian back-arc basin. The Csővár Basin was an extensional intraplatform basin on the passive margin of the Neotethys Ocean during the Late Triassic – Early Jurassic.

The studied section exposes the Lower Rhaetian to Hettangian part of the cherty limestones of the Csővár Formation. Based on earlier studies, common occurrence of calcarenitic turbidites with debrite intercalations in the Lower Rhaetian part of the section indicate proximal toe of the slope environment. The Upper Rhaetian portion of the section is predominantly composed of distal carbonate turbidites and radiolaria-rich basinal facies, indicating an overall transgressive trend.

Based on our field observations and UAV-based photogrammetry, extensional soft-sediment structures such as asymmetrical and rotating boudins, pinch and swells, and headwall scarps are mainly found in the Lower Rhaetian part of the studied section. In contrast, contractional soft-sediment structures, including slump folds and duplexes, are more common in the Upper Rhaetian – Hettangian part of the studied section.

The orientation of the measured extensional and contractional soft-sediment structures exhibits significant variation, however, the east-west direction is dominant. The asymmetry of soft-sediment structures indicates an approximately south-dipping slope, in accordance with the map-view facies distribution of the platform to basin transition.

The style and variability of these soft-sediment, most likely syndiagenetic, structures resemble the ductile-brittle transitional domain of tectonic structures. The transition from the extensional to the contractional domain is in accordance with the change from proximal to distal toe-of-slope facies upward in the section and indicates the deepening of the basin.

Zircon in different textural positions as an important indicator for multi-stage evolution of metagabbroic rocks: insights from the Teplá-Barrandian Unit, Bohemian Massif

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The gabbroic rocks are commonly spared by complete reworking during metamorphism and it often capture the complete evolution from preserved magmatic stage to metamorphic re-equilibration. Thus, we believe that this kind of lithology represents a promising candidate for studying areas that underwent a polyphase evolution. Samples investigated in this study originate from small metagabbro bodies located along the contact of Teplá-Crystalline and Mariánské-Lázně Complexes located in NW corner of the Teplá-Barrandian Unit in Bohemian Masif. This area is well-known for its complicated evolution which includes several metamorphic events. Detailed petrological study together with U–Pb dating of representative samples allow us to characterize three events (I–III) defined by different textural position of analysed zircon and titanite grains. The oldest Cambrian event I is recorded in isolated matrix-hosted grains that yield similar mean age of c. 500 – 510 Ma in both areas. The second Cambro-Ordovician event II was connected with formation of tiny zircon grains forming rim around ilmenite at ~480 – 490 Ma due to diffusion reaction of ilmenite and surrounding silicate matrix enabled by increase of temperature accompanied by presence of fluid. The youngest Variscan event III is associated with the formation of zircon corona around baddeleyite at ca. 360 – 380 Ma, in most cases original baddeleyite is almost consumed by newly formed zircon. Similar age (c. 370 Ma) was also obtained for titanite forming corona around ilmenite and/or rutile indicating metamorphic re-equilibration. In addition, selected zircon grains from three samples were analysed for texturally controlled U-Pb dating and estimation of trace element concentration of the zircon. Based on the obtained data the tiny zircon grains around ilmenite show lower concentration of REE compared to the zircon grains in the matrix. Zircon corona formed around baddeleyite has generally comparable or slightly lower concentration of REE compared to the newly formed zircons containing only relicts of former baddeleyite. Additionally, the crystallization temperatures were calculated using thermometer by Watson et al. (2006) to get some constraints about processes responsible for development of the three generations of the zircon.

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Sequential replacement of Ti-bearing minerals in a Variscan granulite discriminate several stages during the exhumation of a high-pressure eclogite-bearing unit of the Massif Central (France)

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The retrograde P–T path of a Variscan high-pressure unit in the core of the Massif Central (France) was considered an isothermal decompression followed by cooling. This P–T path was determined qualitatively by previous studies using the secondary assemblage of partially retrogressed eclogites. The present petrological study of a partially overprinted mafic granulite sampled in the same unit provides further details on the P–T evolution.

The studied hand-sample vary from almost pristine high-pressure granulite facies domains essentially consisting of garnet–diopside–plagioclase to partially overprinted domains where common replacement textures contain amphibole. Ti-bearing minerals occur as rutile, titanite or ilmenite. Rutile is included in garnet, plagioclase and titanite whereas titanite and ilmenite occur in the matrix. Titanite is commonly partially or totally replaced by vermicular ilmenite. These observations constrain the sequential replacement of rutile by titanite followed by the replacement of titanite by ilmenite.

Phase equilibrium modelling indicates that the peak high-pressure granulite facies assemblage (garnet–plagioclase–clinopyroxene–rutile–quartz), mineral chemistry (pyrope- and grossular-rich garnet, labradorite, Al-diopside) and reconstructed garnet mode are best reproduced around 10 – 15 kbar and 800 – 1000 °C. Since zircons was not identified in the rock the result of Zr-in-rutile thermometry correspond to a minimum temperature of ~680 °C. Modelling the influence of H_2O on the equilibrium assemblage shows that amphibole and titanite resulted from incomplete hydration during an external fluid influx. Furthermore, titanite, modelled at T < 800 °C, occurs in a range of pressure of 8 – 15 kbar compatible the replacement of rutile by titanite along a P–T path dominated by cooling. On the other hand, the transition from titanite to ilmenite modelled at 7 – 8 kbar is strongly dependent on pressure suggesting another retrogressive stage dominated this time by decompression.

Available data from the studied locality and the newly documented P–T path suggest three metamorphic stages during the exhumation: 1) decompression from the eclogite (20 – 25 kbar, 850 – 900 °C) to the granulite facies (10 – 15 kbar, 800 – 1000 °C); 2) cooling under 800 °C; and 3) further decompression below 8 kbar. The first stage may be related to the exhumation of the high-pressure unit from mantle to crustal depth while subsequent stages could document active thinning of the thick orogenic crust back to normal thickness. This sequence, already reported in other segments of the Variscan belt and beyond provides important constraints for the formulation of tectonic models to explain the exhumation of high-pressure rocks.

Petrography of tectonic veins in a Middle Permian–Early Triassic sequence, SW Hungary

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In the following decades, Hungary needs to establish a deep geological repository to accommodate high-level radioactive waste. The research area for this purpose is the Western Mecsek region, as preliminary assessments have identified the Boda Claystone Formation (BCF) as a promising host rock. However, fluid migration along fractures may pose challenges for long-term containment. Mineral veins associated with migration of paleofluids have been the subject of numerous studies and are currently under further investigation. The present study aims to characterize the mineralogical composition and crystal morphology of tectonic veins within the underlying Middle Permian Cserdi Formation and the overlying Late Permian–Early Triassic Kővágószőlős Sandstone Formation. The objective is to determine whether the mineral veins observed in the claystone body are also present in these adjacent formations, providing insights into whether the structural evolution and fluid transport processes identified in the BCF have influenced both older and younger formations. This research presents petrographic results obtained through polarized light microscopy, cathodoluminescence microscopy, and Raman microspectroscopy. In the BAF-4 borehole of the Cserdi Formation, which predates the BCF, ~0.5 cm thick mineral veins exhibit a straight, planar morphology. These veins predominantly contain euhedral quartz and blocky dolomite crystals, indicative of a syntaxial vein growth mechanism and advective fluid flow along open fractures. Similar veins, containing 2–3 generations of quartz with minor dolomite, are also observed in the Middle Permian Gyűrűfű Lapilli Tuff Formation, which underlies the Cserdi Formation. In contrast, in the BAT-4 borehole of the younger, Kővágószőlős Sandstone Formation, 3–4 mm thin veins contain fine-grained and blocky calcite, dolomite, barite, and quartz, similarly suggesting syntaxial vein growth and advective fluid flow. In thicker veins (0.5 – 1 cm), anhedral dolomite and blocky calcite are accompanied by abundant angular wall-rock inclusions. Previous studies identified at least four (BAF-2 borehole) and up to six (BAF-3 borehole) distinct vein generations within the BCF, predominantly filled by calcite. Older veins frequently contain albite, while anhydrite, barite, and celestine are also present in several cases. Dolomite and quartz are rare in BAF-2 but occur in BAF-3 and BAF-4 boreholes with similar morphologies to those observed in the Cserdi and Kővágószőlős Sandstone Formations. This suggests that the mineral veins found in the formations both older and younger than the BCF may share a common genetic origin with those identified in the claystone itself. Ongoing fluid inclusion analysis, C—O stable isotope measurements, clumped isotope and strontium isotope studies will provide further clarification on the genetic relationships and fluid evolution processes affecting these formations.

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Metamorphic record of subduction in metapelites of the Saxothuringian orogenic wedge

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Orogenic wedges represent large-scale geological structures that form at convergent plate margins as a result of subduction to continental collision processes. The Saxothuringian orogenic wedge is an example of such a structure in the western part of the Variscan Bohemian Massif. The wedge is formed by a variegated assemblage of rocks metamorphosed at different stages of the wedge development. Among these, metapelitic rocks provide valuable insights into the wedge evolution since they are abundant and their metamorphic record is relatively easy to decipher. In this contribution, we focus on the early subduction history recorded in metapelites of the Erzgebirge Mts. with the aim to understand the present-day spatial distribution of different depth levels of the original subduction complex.

Altogether nine metapelite samples were selected and studied in detail. Based on their location and mineral assemblage, the samples can be divided into three groups: 1) phyllite group, coming from the outer wedge, 2) micaschist west group, coming from the transition zone between the outer and inner wedge, and 3) micaschist east group, coming from the transition zone and inner wedge as previously defined by Jouvent et al. (2023). The phyllite group samples are mainly characterised by quartz, phengitic muscovite (Si up to 3.28 apfu), rutile, chlorite ± paragonite. The chloritoid porphyroblasts (X_{Mg}=0.07 – 0.09) are present in the sample from the lower part of the outer wedge. The micaschist west group samples are primarily composed of quartz, phengitic muscovite (Si up to 3.45 apfu), garnet, rutile, ilmenite, chlorite, biotite. Inclusions of chloritoid (X_{Mg}=0.11 – 0.13) are observed in garnet porphyroblasts in the sample close to the boundary with the outer wedge. Garnet in this sample indicates prograde compositional zoning with three distinct zones, core, rim I, rim II, showing decrease in grossular (0.18 $\rightarrow$ 0.01) and spessartine (0.08 $\rightarrow$ 0.002), and increase in pyrope (0.04 $\rightarrow$ 0.16), almandine (0.71 $\rightarrow$ 0.88) and X_{Mg} (0.05 $\rightarrow$ 0.16) towards the rim. Compositional jump in almandine and grossular is observed between the rim I and II. The micaschist east group samples dominantly consist of quartz, phengitic muscovite (Si up to 3.43 apfu), rutile, ilmenite, chlorite, biotite ± kyanite. Chloritoid is present either in matrix (X_{Mg}=0.14 – 0.34) or as garnet inclusions (X_{Mg}=0.11 – 0.25). The prograde zoning of garnet in the kyanite-garnet micaschist is characterised by two distinct compositional zones, core and rim, that show rimward decrease in grossular (0.09 $\rightarrow$ 0.01) and spessartine (0.09 $\rightarrow$ 0.001), and increase in pyrope (0.05 $\rightarrow$ 0.18), almandine (0.77 $\rightarrow$ 0.86) and X_{Mg} (0.06 $\rightarrow$ 0.19).

Our preliminary thermodynamic modelling results suggest that differences in mineral chemistry among the individual sample groups can be attributed to differences in PT conditions increasing towards the inner part of the Saxothuringian orogenic wedge (Jouvent et al., 2022; Kulhánek and Faryad 2023).

Age, variability and origin of the gabbros–granodiorites in the Nasavrky Plutonic Complex (Železné Hory Mts, Bohemian Massif)

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Within the European Variscan Belt, relics of Devonian–Mississippian arc-related, pre-collisional magmatic rocks are scarce, especially in France–Iberia. This is mainly due to intense tectonomagmatic reworking during subsequent, collision-related evolution. In contrast, in the central parts of the Bohemian Massif, several of these Palaeovariscan arc complexes are well preserved, mostly decorating the boundary between the low-grade to unmetamorphosed Teplá–Barrandian Unit and the high-grade Moldanubian orogenic root.

One of the largest (600 km^2) and most varied among these, the Nasavrky Plutonic Complex, has been subdivided into (1) an older central–southern domain comprising high-K calc-alkaline (Amp-)Bt tonalites–granodiorites with K-poor, mainly tholeiitic mafic bodies (Amp gabbros to Bt-Amp quartz diorites), and (2) a younger northern domain dominated by red Bt granites. Preliminary geobarometry shows that amphibole in the older mafic rocks crystallized at shallow crustal levels (1 to 2 kbar, i.e. ~7 – 3 km); the younger pink granite was already subvolcanic.

Four samples of gabbros–granodiorites were newly dated using the LA ICP-MS U–Pb method on zircon. The resulting concordia ages range between 347.2 ± 2.1 Ma and 340.5 ± 2.0 Ma. The bulk-crust two-stage depleted-mantle Hf model ages (T_{DM}^{Hf}) for the intermediate–felsic rocks range between 0.81 and 1.70 Ga. Xenocrysts in the mafic bodies are mainly Ediacaran–Cryogenian, i.e. coming from the Neoproterozoic country rocks, and yield T_{DM}^{Hf} of ~1.51 – 1.68 Ga. The intermediate–felsic samples are virtually inheritance-free.

The studied gabbros–granodiorites are all subaluminous, with trace-element geochemical signature characterized by a strong enrichment in hydrous-fluid-mobile Large Ion Lithophile Elements (LILE; Cs, Rb, Ba, Th, U, K) over conservative High Field Strength Elements (HFSE; Nb, Ta, Ti) – a hallmark of a magmatic-arc setting. There is strong field, petrological and geochemical evidence for vigorous interaction and hybridization between contemporaneous mafic and felsic melts. The former were derived from a strongly depleted, subduction-modified mantle source ($^{87}Sr/^{86}Sr_{345}$ < 0.704, εNd_{345} > +6.8), while the latter came from immature crust ($^{87}Sr/^{86}Sr_{345}$ > 0.708, $\varepsilon Nd_{(i)}$ < −4.5) and were likely generated by partial melting of potassium-rich metabasic rocks.

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Tectonics of the Polička Fault – preliminary results (Czechia)

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The aim of the paper is to summarize the existing knowledge and to bring new information about the tectonics of the Polička fault. The Polička Fault is a system of faults in the southeastern part of the Bohemian Cretaceous Basin at the contact between Cretaceous sediments and the Polička Crystalline Unit. Previous authors have characterized the Polička fault zone as a system of normal faults in the SSW–NNE direction fragmented by strike-slip faults. These faults were determined mainly according to stratigraphy by the throw of fault lines breaking individual strata of the Bohemian Cretaceous Basin.

The new research focused on kinematic indicators – microfault planes, striation systems and mineral accretion steps on microfault surfaces. The evaluation of dip azimuth and dip of microfault planes and striations (68 data from 4 sites so far) to determine the trend of palaeostress was carried out using the programme MARK.

There were determined normal faults, sinistral subhorizontal slips, oblique slips or slips without a sense of movement. The oriented slips, which the software assigned a thrust trend, were superposed to the normal faults, so they are relatively younger. Paleostress analysis revealed a phase of extension in the trend W–E (σ_1 subvertical, σ_3 subhorizontal), a phase of older compression in the direction NW–SE (σ_3 subvertical, σ_1 subhorizontal) and a phase of younger compression in the NE–SW direction (σ_3 subvertical, σ_1 subhorizontal).

The extension seems to have taken place in the middle Oligocene–Early Miocene, with the nearest centre of neovolcanism located in the vicinity of the town Luže in the Chrudim district. The NE–SW compression may reflect the Early Miocene shortening from the Eastern Alps. NW–SE compression is probably post-Miocene. In the zone of fault line crossing, synkinematic or possibly prekinematic ferruginization of probably (pre)mid-Oligocene age was observed on striated quartz microfault planes.

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The metasediments of the Zábřeh Crystalline Unit

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The Zábřeh Crystalline Unit (ZCU) is situated on the eastern margin of the Bohemian Massif and is rimming the Orlica-Snieznik Dome from the south. It represents a metamorphosed volcanosedimentary complex with increasing degree of metamorphism towards north. The unit is divided into the southern and northern part with a narrow zone of Cambro-Ordovician metabasic rocks in the middle as a dividing horizon.

The study shows geochemical and geochronological data of four samples of metasediments. The U–Pb isotopic data on zircon grains was combined with whole-rock geochemical data to constrain the maximal depositional age of sediments, sedimentary provenance and tectonic settings of the former sedimentary basin(s) now forming the ZCU.

The metasediments are classified as greywackes and litharenites (classification after Pettijohn et al., 1972) and as wackes with higher ratio of Fe_2O_3 / K_2O (classification after Herron, 1988). The samples show a negative Eu anomaly in the chondrite-normalized diagram of Rare Earth Elements. In the diagram for the tectonic discrimination of sediment provenance using contents of TiO_2 as a function of contents of Fe_2O_3 + MgO, the samples plot in the fields of active continental margin to continental arc.

The metasediments from the northern part of ZCU are represented by fine- to medium-grained quarzitic phyllites and yielded detrital age spectra with dominant Cambrian to lower Ordovician population (460 – 520 Ma) and clusters of Paleoproterozoic age (1.8 – 2.2 Ga). On the other hand, both the fine-grained metagreywacke and the metaconglomerate from the southern part of ZCU yielded the upper Neoproterozoic (Ediacaran) age, 547.7 ± 8.1 Ma and 537 ± 4 Ma. The age spectra can be correlated with other units of the Bohemian Massif and they show a typical distribution of the Cambro-Ordovician sequence of Peri-Gondwana with significant affinity to the West African Craton.

We conclude that the ZCU consists of the relatively older southern part represented by the coarser grained metasediments and the relatively younger fine-grained metasediments in the north. During the Cambro-Ordovician rifting along the Gondwana margin, mafic magmas were intruded into the coarser grained (meta)sediments and the fine-grained sediments were syn-tectonically deposited to the north.

Medieval earthquakes at the western margin of the Bohemian Massif (Czechia) – archaeological and historical evidence

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The Bohemian Massif has been considered a particularly stable area of Europe seismically and tectonically. We do challenge this opinion by revealing evidence of earthquake-induced deformation and destruction in Medieval buildings in the town of Cheb / Eger. Edifices of the castle (Black Tower, palace, double chapel, smokehouse), St. Nicholas church, and downtown buildings bear deformation features attributable to earthquakes. Dropped keystones, in-plane extension between ashlars, fractures penetrating blocks, tilted, twisted, and bulging walls, soft floor effect on load-bearing walls, a shifted column, U-shaped collapse are conspicuous features of Medieval edifices. Additionally, evidence for repair (various apron buttresses) characterize buildings built through the 11th to 15th centuries. Dates of damage are constrained by dendrochronology, known dates of change in architectural style from Romanesque and Gothic, and interpretation of direct and indirect historical records. Historical information on felt earthquakes in the 17th–20th century does not record major damage in Cheb. We hypothesize that I = VII-IX earthquake(s) damaged Cheb in the Middle Ages, potentially caused by the Mariánské Lázně Fault.

Tectonic Architecture of the Erzgebirge/Krušné Hory

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We present a new scheme for the tectono-metamorphic architecture of the Erzgebirge. While we follow the scheme of previous studies (Konopásek & Schulmann, 2005; Rötzler & Pleesen, 2010) we made significant changes based on our study of the distribution of high-pressure metamorphism. Our model consists from bottom to top of the following levels: (1) a Lower Gneiss Unit (LGU) that consists of gneisses with both Proterozoic and Ordovician protoliths and experienced amphibolite-facies peak metamorphism; (2) an Upper Gneiss Unit (UGU) that consists of a UHP-metamorphic subunit mainly made from Ordovician protoliths. This UHP unit is sandwiched between a mixed HP gneiss unit dominated by Proterozoic meta-greywackes, but also containing Ordovician complexes. We observe HP eclogites throughout this entire gneiss matrix and do not support models of and eclogite free tectonic level in the UGU; (3) a Mica Schist Unit (MSU) that likewise consists of two subunits: firstly, a MSU sensu stricto made of Ordovician metasediments and rare amphibolite, which experienced only amphibolite-facies peak conditions. Secondly, an internal nappe, that consists of HP-gneisses and eclogites from various Ordovician protoliths. The structural position and the extent of this HP subunit, especially the relation to the HP rocks in the UGU remain enigmatic. We propose fundamental tectonic boundaries between all mentioned units and subunits in the area.

The Staré mesto granite – an older granite in the Malé Karpaty Mts. (Tatric unit, Western Carpathians)

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Genesis of the granitic rocks from the Western Carpathians is mostly related to the subduction/collisional processes. The Variscan granitic magmatism, in the CWC, began by the Late Devonian subduction-related "immature" granitic rocks and/or diatexites having ages ca. 370 – 360 Ma, which form the small, apical, unhomogenized parts of plutons. The early oceanic slab break-off and ensuing asthenospheric upwelling enhanced the granite formation before ca. 360 – 357 Ma (Broska et al., 2022), and most of the diorites come from this period. This was followed by the Early Carboniferous (Tournaisian, 357 – 345 Ma) collisional, massive flare up of the calk-alkaline & peraluminous I/S hybrid granitoides representing dominant granitic suite within the CWC that typically occur in core mountains of the Tatric Unit and within the Veporic composite batholith. Though, when the character of the Variscan Orogen changed, from convergent to divergent due to extensional crustal thinning, decompression melting occurred during rapid uplift and exhumation in the post-collisional, Visean period at ca. 345 – 335 Ma. However, when we recently studied the molybdenites at the Trojárová deposit near Pezinok, the new Re—Os ages surprised us, since we obtained two different ages from two different forms of molybdenites in one sample (Kohút et al., 2024). Large flaked molybdenite from the foliation shear plane, of the Staré mesto granite yielded an age of 356.7 ± 2.6 Ma – consistent with the age of the Bratislava Massif granites; whereas fine-grained molybdenite from the greisenized leucogranite endo-contact yielded a significantly higher age of 368.6 ± 1.4 Ma, which provoked our attention. Later, during detailed analysis of the host granite, we found that this higher age coincides with the magmatic age of the Staré mesto granite (e.g., the CHIME age of monazites of 360.0 ± 4.5 Ma and the new SHRIMP zircon dating with a concordia age of 365.3 ± 5.6 Ma). So-called Staré mesto granite (SMG) is medium grained, peraluminous, biotite–muscovite leucogranite, having elevated values of silica and alkali's (SiO_2 = 72.9 – 75.6 wt.%, Na_2O = 3.6 – 4.1 wt.%, K_2O = 3.4 – 4.3 wt.%); moderate Al_2O_3 = 14.4 – 14.8 wt.%; along with lower values of iron and magnesium (FeOt = 0.8 – 1.8 wt.%, MgO = 0.1 – 0.4 wt.%), and low content of the REE ($\leq$80 – 88 ppm) with La_N/Yb_N = 16.3 – 17.3 and Eu/Eu* = 0.68 – 0.71. Although according to the geological map of the Malé Karpaty Mts. (Polák et al., 2011) the SMG seems to be an analogue to the common two-mica granites of the Bratislava Massif; actually, it forms non-homogenized older part on the top of the Bratislava Granite Massif.

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Seismic and Field Traces of the Holešov and the Kroměříž faults

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The Holešov and Kroměříž faults are located at the boundary between the Outer Western Carpathians and the Bohemian Massif. The depression delineated by these two faults is known as the Upper Moravian Basin. The Holešov Fault is situated at the northeastern boundary of this structure, whereas the Kroměříž Fault is positioned at the southwestern boundary. To characterize these faults, a combination of dozens of two-dimensional seismic profiles and multiple borehole datasets was used. Data were imported and processed using Petrel software, allowing analysis of stratigraphic horizons and dislocations that intersect them.

Three geological units were interpreted in this area: the Variscan basement of the Bohemian Massif, the autochthonous Neogene sedimentary cover, and the flysch nappes of the Outer Western Carpathians. These units are separated by two prominent stratigraphic surfaces: the nonconformity between the Neogene sedimentary rocks and the basement and the thrust surface of the nappes. Variations in the thickness of the Neogene deposits allowed us to distinguish between synsedimentary and post-sedimentary fault activity. Two sets of local faults were identified, mainly differing in their geological age of activity.

1. First-stage faults – These faults were active during the deposition of Neogene sediments, influencing the sedimentary processes. Their activity is reflected in the thickness variations of the sedimentary layers on either side of the faults, indicating differential subsidence and changes in the localized accommodation space. Such variations suggest that the movement along the faults occurred contemporaneously with sedimentation, leading to an uneven distribution of the deposits. These faults affect both the Variscan basement and the bedding of the autochthonous Neogene but do not disrupt the upper lying flysch nappes. Their formation preceded the thrusting of the Carpathian flysch rocks.

2. Second-stage faults – These faults affect all units considered, including the flysch nappes. Therefore, it indicates that they are younger in age. They became active only after the completion of the Neogene sedimentation. Since the faults occurred after deposition, the sedimentary layers on both sides of the fault exhibit a uniform thickness, indicating that the displacement was purely structural and did not influence the original depositional processes. These faults should be associated with later tectonic events.

The seismic profiles indicate that both major faults were active during both the first and second stages of deformation. Both faults exhibit a normal-fault character, with the Holešov Fault dipping to the southwest and showing a maximum offset of 735 m in the Variscan basement. On the Kroměříž Fault dips to the northeast, with an offset of 990 m.

What to do, when you “see nothing” in the field? Case of the Glinno Graben on top of the Góry Sowie Massif (the Sudetes, NE Bohemian Massif, SW Poland)

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Detailed geological mapping is the first step in mineral and energy resource exploration, natural hazard assessment as well as groundwater management, serving as a fundamental tool for understanding geological structures of different origins. However, what can be done when the degree of rock exposure or the presence of weathering cover in a mountainous area being mapped do not allow for precise determination of lithological or tectonic boundaries? To address this challenging task, we employed traditional geological field mapping, exploratory trenches, LiDAR-derived digital elevation model (DEM) analysis, and shallow electrical resistivity tomography (ERT). These methods were used to investigate remnants of a Mississippian sedimentary succession preserved atop the uplifted western part of the Góry Sowie Massif (GSM), SW Poland, where rock exposure is extremely poor. The Carboniferous of the GSM, historically referred to as the ‘Culm of the Sowie Mountains’, occurs on the upthrown side of the major Sudetic Marginal Fault within several small, predominantly NW-SE trending, tectonic grabens and half-grabens. It is found within several small, predominantly NW-SE trending tectonic grabens and half-grabens, including those of Walim, Glinno, Kamionki, and Sokolec-Jugów. The Culm strata, comprising middle Viséan to Namurian continental and marine deposits up to 300 meters thick, are lithologically subdivided into the Walim/Jugów (continental), Sokolec (shallow marine/deltaic), and Kamionki (deltaic) formations.

The Glinno Graben (GG), approximately 7.5 km long and up to 1.5 km wide, displays an asymmetric, irregular structure and consists of three tectonic subunits. Its northernmost part reveals a WNW-ESE-striking half-graben structure, filled with gneissic conglomerates and sandstones of the Walim Formation that dip gently at 15 to 20° to the SW and are intersected by narrow, WNW-ESE-trending lamprophyre dykes. To the south, the half-graben merges with a NNE-SSW-oriented fault-bounded horst, covered by a thin carpet of gneissic conglomerates. The middle sector of the GG manifests itself in the field as a topographic depression, bounded by nearly parallel, NW-SE-trending faults (the Western and Eastern Glinno faults) with total trace lengths of approximately 6.5 km (WF) and 4 km (EF), exposing only gneissic conglomerates. The southernmost part of the graben features a morphological elevation exposing sandstones and mudstones of the Sokolec Formation, which define a distinct residual outlier (Ostrzew Hill; 551 m a.s.l.), rising approximately 150 m above the flat topographical bottom of the graben.

Our study has shown that modern geological mapping must rely on multiple complementary methods. It also demonstrated that strong lithological contrasts between the sedimentary fill of the graben and its crystalline shoulders and floor make resistivity geophysical methods a valuable tool for investigating its internal structure. The marginal faults of the graben were clearly interpretable on all the obtained ERT cross-sections.

Influence of caprock on extrusion style and shallow deformation of salt diapirs

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Growing salt diapirs emerging at the sedimentary surface can produce outflowing salt extrusions in form of salt bulges or glaciers, as observed in many places worldwide. The growth rate of salt diapirs usually oscillates depending on several factors and can be arrested by depletion of the source layer or diapir burial, accompanied by sequencing the passive and active diapirism. The bulges of such diapirs are also affected by meteoric water, which dissolves the salt and leaves behind insoluble material embedded within the source layer, forming the so called caprock. The caprock layer is assumed to be already developed before the reactivation stage during regional shortening and hence it may play a role in the development of the ongoing salt extrusions. Geometry, composition and mechanical properties of the caprock itself can vary widely depending on factors such as original composition of diapiric material, salt dissolution and growth rates, etc. However, the exact bulk mechanical properties of any caprock remain poorly understood and therefore their impact on overall diapiric bulge evolution is currently mostly unknown.

In order to understand impact of such coupled parameters on style of diapirism, we employed 2D numerical modelling utilizing the finite element method and complementary sandbox analogue modelling to expand investigations to 3D. We focused on the effect of geometry and rheology of the caprock layer in various tectonics regimes. In numerical modelling, we quantified both, dynamic and geometric aspects of salt and caprock evolution within the series of derived bulk parameters on which we performed the multivariate statistical analysis. In analogue modelling, we investigated surface morphology and time variation of deformation fields.

Our results show that in selected ranges of tested parameters clearly dominates the effect of caprock cohesion to bulge geometric evolution while the overall rate of spreading and localized strain rates are rather driven by tectonic scenario. The fastest extrusion and spatially largest diapirs with glacier-style flow are those in combined regime, where the salt-rich basements of high buoyancy potential simultaneously experiences the compression regime Our results thus might help to determine the behavior of regionally widespread diapirs within the orogens such as the Zagros and provide insight to coupled composition-tectonic effects on their surface dynamics.

GeoTwin: Digital twin of the Bieszczady Mountains – Project concept

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Understanding geological structures is essential for interpreting landscape evolution, geohazard assessment, and geotourism development. The Bieszczady Mountains, part of the Outer Carpathians, contain complex fault systems and tectonic features that remain underexplored. Despite the region's popularity, its geological heritage is often overshadowed by its biodiversity.

The GeoTwin project aims to develop a Digital Twin of the Bieszczady Mountains, integrating high-resolution remote sensing, LiDAR, and photogrammetry with field-based structural analysis. This virtual 3D model will provide a comprehensive, interactive platform for geotourism, education, and scientific research.

Preliminary analysis using GIS and remote sensing will identify key geological sites, followed by detailed field investigations using drone-based photogrammetry. Structural features, such as faults and folds, will be mapped and analyzed through integrated LiDAR and outcrop-scale observations. The Digital Twin will allow real-time exploration of these structures, offering insights into their formation and evolution.

The project will enhance geological mapping accuracy and promote sustainable tourism by minimizing environmental impact. By combining digital tools with traditional field studies, GeoTwin will advance geological heritage interpretation and set a framework for similar initiatives in other geologically significant regions.

Expected outcomes include a detailed 3D geological model of key sites in the Bieszczady Mountains, improved identification of structural features, and an accessible digital platform for education and geotourism. The project will provide a novel tool for scientific research, helping to refine geological interpretations while fostering a broader public understanding of the region's geodiversity. Additionally, the Digital Twin will serve as a foundation for future applications in geological monitoring and conservation efforts.

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Experimental synthesis of garnet reference materials for in situ lithium isotope analysis in subduction zone garnets

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Research on trace element fractionation enhances our understanding of metamorphic processes. In particular, lithium (Li) can be used to track the redistribution of material and the mobility of fluids in subduction zones with minimal isotopic alteration during high-grade metamorphism. Variations in Li content and isotopic ($^{7}Li/^{6}Li$) composition offer insights into Li behaviour during metamorphism. In situ Li isotope analysis of garnet is valuable for its stability, prevalence, and preservation of compositional zoning along the P-T path. The main challenge in Li isotope analysis by the secondary ion mass spectrometry (SIMS) appears to be in the matrix effects due to compositional variability. The analysis thus requires an adequate reference material, similar to the studied natural garnet, which we attempted to synthetize in this study.

We used 9465 garnet analyses extracted from previous studies on continental subduction in Krušné hory Mts. to assess their compositional variation. Principal component analysis identified ten representative compositions for future SIMS reference materials. Compositional mixtures with 100 ppm Li and corresponding phosphorus or yttrium amounts were prepared to synthesise garnet with high-pressure stable coupled substitutions of $^{VIII}Li^{+}$ + $^{IV}P^{5+}$ or $^{VIII}Y^{3+}$ + $^{VIII}Li^{+}$, respectively. In the first step, we synthesised homogeneous glasses of appropriate garnet compositions from high purity chemical reagents in a vertical gas mixing furnace at an oxygen fugacity two log units below the quartz-magnetite-fayalite buffer. Such glasses can be directly used as SIMS standards. Secondly, we attempted to prepare homogeneous garnet crystals from the previously synthesised and fine-ground glasses in the piston cylinder apparatus at 2 GPa and 1200 °C using graphite-platinum double capsules. The P-T stability of the target compositions was determined by the thermodynamic modelling in Perple_X software. Successful runs produced homogeneous 100 – 200 µm garnet crystals with minor volume of interstitial glass. EPMA and LA-ICP-MS analyses confirmed the desired composition of produced garnets with the trace lithium levels, and compositional homogeneity. The resulting materials are therefore suitable for future SIMS analysis and comparison of the effect of material structure (amorphous versus crystalline material).

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Geophysical and structural study of the Permian Uranium mineralization in the north-eastern part of the Třebíč Massif

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We provide a re-evaluation of Carboniferous and Permian orogenic fabrics of the north-eastern Moldanubian region, including the north-east part of the Třebíč syenite massif. The study includes gravity and magnetic analyses and evaluation of existing structural and geochrnology data. These datasets are used to characterize the orogenic architecture resulting from Carboniferous polyphase deformation of eastern margin of the Bohemian Massif including intrusive and post-intrusive deformation of the Třebíč massif. This complex architecture resulted from two principal Variscan orogenic cycles intimately linked to emplacement of the syenitic magma in the middle crust and its subsequent solid state deformation. It is well known that this magmatism is related exceptional and unique enrichment of radiogenic elements. The Carboniferous edifice was later reworked by early Permian dextral and sinistral strike slip zones, magmatism and deposition of sedimentary basins. This event was also associated to important Uranium mineralization in the region close to the Třebíč massif related to late strike slip shearing.

It was previously proposed that the U mineralization was genetically linked to the Třebíč syenite due to its Permian leaching. However, the source of fluids leaching the U-enriched bodies, pathways of these fluids final formation of the U mineralization remain unknown. Our study is focused on characterization of two main events related to emplacement of U rich magma, its intergration into collisional orogenic architecture and its reworking by later Permian deformation related to the formation of U deposit. Gravity and magnetic anomalies, revision of structural and geochronological data will be used to provide first and preliminary insight into geometrical and temporal relationships between these two stages of U accumulation in the crust.

Disequilibrium enhanced equilibration: Dynamics and textural evolution of cumulate interface

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Textural characteristics and evolution of mafic cumulate rocks have been an active point of discussion between igneous petrologists for over sixty years. In order to answer which processes take part in cumulate formation and preservation of their characteristic features, detailed studies of their primary textural attributes are likely the key to the majority of current disputes. However, due to the inaccessibility of the environment in which cumulates form, the research is largely dependent on observations of solidified mafic magma chambers, which supposedly do not retain most of the primary textures due to equilibration, later alterations, and weathering. Therefore, diverse experimental methodologies are being employed instead, allowing research of cumulate formation in moderated conditions.

In the presented study, we utilize a new methodology of high-temperature experiments to observe textural development of a newly formed cumulate over a period of time, with special focus on the interface area between the crystals and the bulk melt above. The environment of a natural magmatic intrusion is simulated by using an artificial suspension of olivine crystal fragments in a haplobasaltic liquid, sealed within a graphite capsule. The crystal suspension was subjected to a two-hour heating period at a liquidus temperature (1500 °C), during which the cumulate formed by settling, followed by inducing undercooled conditions (1460 °C) in order to promote grain growth inside the cumulate. The experiments ranged in length, from one to forty-six hours in undercooled environment, in order observe a progressive textural evolution over a prolonged time period. A total of 7 selected samples were then subjected to detailed textural analysis. The interface area and the deeper portions of the cumulate were evaluated separately, in order to study the textural evolution and corresponding processes taking place in each section.

Textural analysis of the cumulate interface shows a complex series of processes, including a transition from fast kinetic growth in the early stages of undercooling, into a less vigorous equilibration stage dominating the rest of the experimental series. The kinetic growth phase is characterized by sharp skeletal overgrowths encapsulating the seed crystals, which became the focus points of the subsequent equilibration. The skeletal shapes were progressively transformed into cellular morphologies and ultimately into near smooth, equant grains, resulting in complete erasure of the kinetic stage after forty-six hours. Deeper portions of the cumulate, however, did not show any of the evolution described above, acting as a closed system instead. The observed discrepancies pointed to a specific yet so far undescribed behaviour, now termed as 'disequilibrium enhanced equilibration', from which we can draw a number of major conclusions regarding the preservation of cumulate textures, common interpretations of olivine morphology, and processes of crystal growth.

Were the Kalahari and Congo cratons adjacent or apart in the Rodinia Supercontinent? A U-Pb detrital zircon investigation of the Central Zone of the Damara Belt, Namibia

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The Congo and Kalahari cratons collided during Gondwana Supercontinent assembly to form the Pan-African Damara Belt at 590 – 470 Ma. Collision followed north-westward subduction, and consumption of the intervening Khomas Ocean. The proposed southernmost extension of the Congo Craton is located in the upper plate arc region, the Central Zone of the Damara Belt, while vestiges of the Khomas Ocean are preserved in the accretionary prism located directly to the south. Neoproterozoic meta-sedimentary rocks of the Damara Supergroup, comprising basal rift-related sediments, overlying passive margin sequences, and upper flysch to molasse deposits were developed across most of the orogen. The width of the Khomas Ocean is debated, hinging on the relative positions of Kalahari and Congo cratons in Rodinia prior to its breakup. Two models exist in this regard. The first model places the cratons close to one another in Rodinia, subsequently separated by a narrow Khomas Ocean and followed by inversion, convergence and collision to give rise to the Damara Belt. This model is mostly based on the lack of HP rocks that would mark a suture zone. The second model states that the two cratons were apart in Rodinia and separated by a wide Khomas Ocean following Rodinia break-up. This model is based on contrasting provenances for Damara Supergroup rocks from the southern, central, and northern parts of the orogen. However, the provenance of these rocks in the Central Zone is understudied, warranting further investigation.

To test these models, we use detrital zircon U-Pb geochronology of the Central Zone basement (the Abbabis Metamorphic Complex - AMC) and overlying basal meta-sedimentary rocks of the Damara Supergroup (Etusis Formation) to investigate their provenances. Preliminary U-Pb geochronology results reveal that these rocks contain major Paleoproterozoic and Meso- to Neoproterozoic detrital zircon age peaks at 2080 – 1920 Ma (AMC), 2160 – 1760 Ma (Etusis Formation), and 1080 – 920 Ma (Etusis Formation). Etusis Formation rocks are interpreted to be proximal reworking of the underlying AMC basement, as well as containing contributions from other sources. These age peaks are similar to those reported from rocks from the northern parts of the Kalahari Craton (e.g., the Rehoboth Province, and Namaqua-Natal Belt) with the younger peak being mostly absent in the southern Congo Craton in Namibia. These results tentatively suggest that the Central Zone may be of Kalahari Craton affinity, questioning; 1) if the main suture zone between the two cratons is located to the north of the Central Zone, 2) if the Khomas Ocean was rather a minor ocean that rifted the leading edge of the Kalahari Craton during Rodinia breakup, or 3) if the Kalahari and Congo cratons were apart in Rodinia.

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Numerical simulations of subduction, relamination and accretion of magmatic arcs

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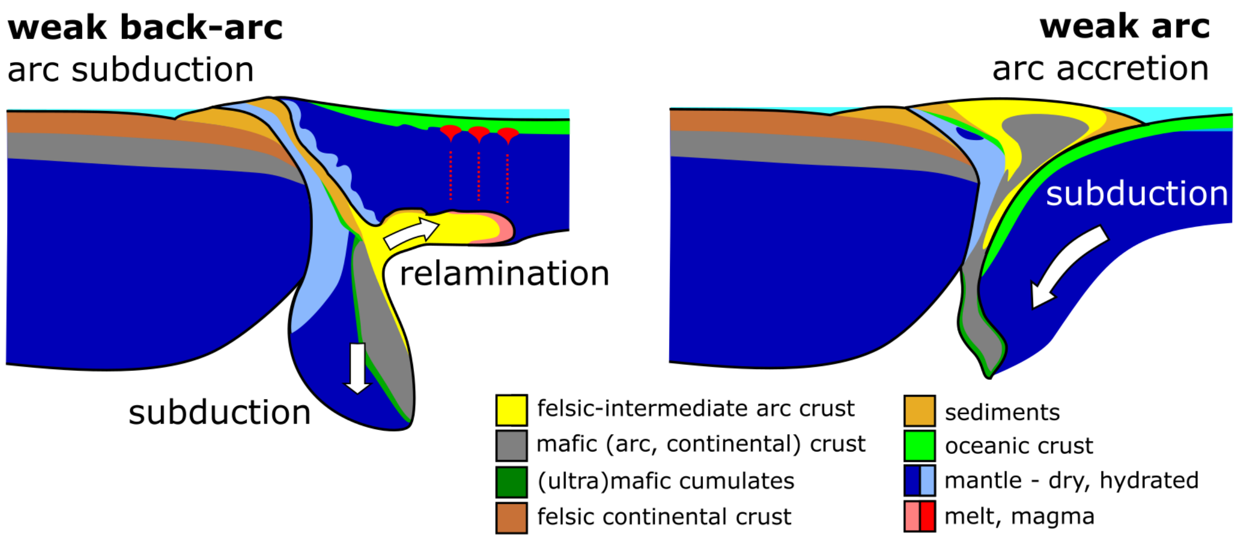
Magmatic arcs above subduction zones, together with warm back-arc regions, are zones of weakness that localize intra-plate deformation. We use two-dimensional thermo-mechanical numerical models to investigate the potential role of these weak zones in the initiation of new subductions. Our models mimic the final phase of oceanic subduction beneath an oceanic plate with well-developed arc and backarc regions, the arrival of a continental plate to the trench and the deformation of the continent–arc–backarc system.

We distinguish two contrasting styles of evolution: 1) Formation of a new plate boundary in the weak backarc and subduction of the arc at this boundary. During this process, the arc crust is partly accreted to the continental margin and partly dragged into the mantle. In the mantle, the buoyant part of the arc crust separates from the rest of the arc lithosphere and flows beneath the lithosphere of the upper plate (relaminates). The relaminated material resides in contact with the hot asthenosphere, warms up and melts, providing the source for magmatism in the upper plate. 2) Formation of a new subduction zone underneath the arc and accretion of the arc to the continental margin. The new subduction zone has an opposite polarity than the original oceanic subduction.

The main parameter that governs the development of these evolutionary styles is the strength of the arc–backarc region. Arc subduction is preferred if the arc is relatively strong compared to the backarc. Arc accretion and initiation of subduction beneath it occur if the arc is very weak due to a high temperature or weak lithology. We discuss the similarities of our models with active and fossil arc systems, such as the Sunda-Banda arc, the Kohistan arc and remnants of oceanic arcs in the Central Asian Orogenic Belt.



Late Neoproterozoic metamorphism in Svalbard: anomalous entity or an effect of a larger scale orogenic event?

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A growing record of late Neoproterozoic tectonothermal events in Svalbard and other parts of the High Arctic region calls for better understanding its bearing on large-scale tectonic interpretations. Metamorphism and deformation of c. 640 Ma age have been well-documented in the recent years within the western basement provinces of Svalbard. The rock units preserving late Neoproterozoic structural grain occur as fault-bounded tectonic units interpreted to form independent terranes. However, they occur along the late Silurian-early Devonian sinistral, large-scale, N-S striking, strike-slip system developed within the Svalbard Caledonides. This system can be traced further north-west toward northern Greenland and the Pearya Terrane of Ellesmere Island. Indeed, a record of late Neoproterozoic tectonometamorphic event has also been derived from both regions. South of Svalbard, in the Barents Sea region, existence of a continuation of the same strike-slip system and potential other terranes recording late Neoproterozoic tectonothermal event is postulated. The onshore continuation of this system is thought to be located in the Timanide belt of eastern Baltica. Thus it is conceivable that the late Caledonian strike-slip system dismembered a continuous, potentially orogenic, structure developed along the Rodinia margin. Such an orogenic event can be imagined as a response to the development of a peripheral subduction girdle developed around Rodinia. In this contribution we are going to show several examples of late Neoproterozoic metamorphic units from Svalbard and speculate on their geodynamic significance and bearing on understanding tectonics in the North Atlantic realm.

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From a new conceptual geotectonic model to a geothermal management system: the Budapest Thermal Karst

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The most significant part of the Permo-Mesozoic basement of the NE part of the Transdanubian Range (TR) is represented by Late Triassic platform and intraplatform basin carbonates. This succession was affected by multiphase thrusting and folding during the Late Jurassic–Cretaceous Alpine orogeny. The unconformable Paleogene deposits are divided by the so-called Buda zone into a terrestric to shallow marine carbonate unit, and deeper marine siliciclastic and argillaceous unit, respectively. During the Paleogene, the area was affected first by dextral transtension, then by dextral transpression. The Middle Miocene succession was deposited in an extensional tectonic regime characterized by normal faulting. The Late Miocene thermal subsidence resulted in the formation of a delta, delta-plain and fluvial sedimentary cover in the S-SE-ern part of the region. This was followed by Pleistocene to Recent inversion. The Triassic and Paleogene formations contain cold and hydrothermal karst systems, including hypogenic caves and springs that supply Budapest's thermal baths. The main goal of the study was to model changes in hydraulic heads, temperatures, and water composition resulting from new geothermal facilities, and to create a proactive model for future production scenarios assessing the impact of potential new geothermal facilities.

The reinterpretation of more than 300 deep and 30 thousand shallow boreholes and archive seismic data, the acquisition of a high-resolution 55 km 2D seismic network, and the reprocessing of gravity and geomagnetic datasets resulted in a new 3D geological model. It also became evident that a new geotectonic concept for the Alpine tectonics of the NE part of the TR is needed. We argue that the Cretaceous compressional structures are related to a south-vergent thin-skinned fold-and-thrust belt that resulted in the imbrication of the Triassic–Early Cretaceous sedimentary cover above a shallow detachment within the Triassic succession (Héja et al 2024). The constructed six geological horizons, six formation maps, seven geological-geophysical cross-sections, and a Pre-Cenozoic basement tectonic map, all feed into a consistent geotectonic 3D model. The resulting model serves as the foundation for a 3D hydrodynamic model extended with convective and conductive, density-dependent heat transport. This regional (~4477 km^2) hydrodynamic model, with refined mesh around spring areas, identified critical karst water supply zones and vulnerable regions through visualized maps, supporting decision-making in geothermal exploration.

Radiolarians and monazites: reflection of specific conditions during the mélange formation and exhumation of the Meliata Unit

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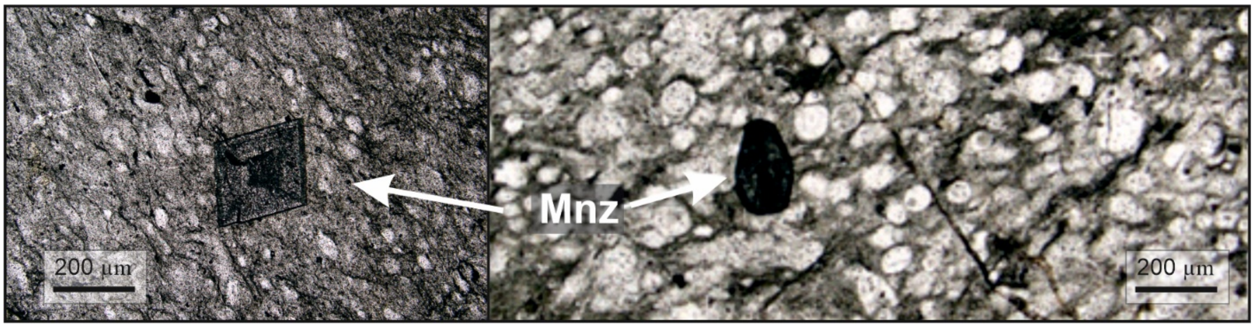
The Meliata Superunit was formed as a result of the closure of the Meliata Ocean and is one of the most significant geological features of the Western Carpathians. The composition of this remnant of ancient ocean is defined by the HP/LT Bôrka Nappe, a low-grade Jurassic sedimentary complex with olistostromes (the Meliata Unit s.s.), and a complicated mélange of polygenous origin with blocks of both of the aforementioned sub-units and ophiolitic rocks (serpentinites, various basalts, radiolarites). The present study focuses on the origin and processes associated with fine-grained marine sediments that represent the mélange matrix. These sediments contain both determinable radiolarians and euhedral post-kinematic monazites (Fig. 1). Our research focused on dark, fine-grained clastic sediments from the Honce and Dobšiná localities, which indicate that the matrix of the polygenous mélange comprises two groups similar in lithology but differing in metamorphic overprint. The first group encompasses unmetamorphosed or very low-grade shales containing Upper Jurassic radiolarians (UA Zone 11). The second group is composed of phyllites, which exhibit a medium to higher-grade mineral assemblage, together with phantoms of radiolarians. The presence of euhedral monazites, whose EPMA U-Th-Pb dating indicates the Early Cretaceous age between 150 and 95 Ma, is characteristic for both groups.

The sedimentation of the studied rocks occurred during the Jurassic epoch. These sediments were partially involved in the subduction process. During the Early Cretaceous, exhumation and forming of an accretionary wedge led to mixing of metamorphosed and unmetamorphosed to low-grade deposits, and subsequently to their reworking into a mélange, accompanied by the incorporation of lithologically variable blocks of older, more resistant rocks. This process is recorded by the growth of post-kinematic monazite porphyroblasts.



Radiolarite with euhedral post-kinematic monazite porphyroblast from Dobšiná.

The research was supported by projects of the Slovak Research and Development Agency (APVV-17-0170; APVV-21-0281), Slovak Grant Agency for Science (VEGA 1/0435/21; 2/0012/24).

German-Polish Caledonides and their connection with the Thor suture

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This presentation provides a comprehensive summary of current knowledge about the German-Polish Caledonides, integrating geological and geophysical data to refine our understanding of the Thor Suture between Avalonia and Baltica. Using reinterpretation of the Basin-9601 seismic profile and a newly constructed 2-D forward gravity model, alongside compiled gravity and magnetic data, we examined the main crustal boundaries. The results reveal that the Caledonian deformation front marks the northern limit of a thin-skinned fold-and-thrust belt. Near Rügen, this belt consists of low-grade Ordovician metasediments derived from the Caledonian accretionary wedge. In Poland, the Pomeranian Caledonides comprise deformed sediments from the Caledonian foreland basin, which were incorporated into the orogenic wedge. The Thor Suture, identified as the thrust of Avalonia's crystalline basement over Baltica, lies approximately 120 km farther south. It extends beneath the North German Basin's depocentre and follows the Dolsk Fault zone in western Poland. The lower crustal edge of Baltica is underthrust southward to the Flechtingen High in Germany, reaching as far as the Variscan Rheno-Hercynian suture at the margin of the Bohemian Massif. Our proposed crustal boundary aligns with the lithospheric mantle necking zone, where the thick lithosphere of Baltica transforms into the thinner lithosphere of Avalonia.

The relationship between rock mass strength and geomorphology in the Bükk Mts, Hungary

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The strength of natural rock masses has been assessed by the authors based on Rock Mass Rating (RMR) of selected outcrops in several study areas in the Bükk Mountains, Hungary. The results revealed that RMR is not the function of rock type but rather the grade of deformation as the resultant discontinuities in the exposed rock masses reduce significantly their strength.

Outcrops with the highest RMR values expose more compact, continuous rock masses that form major peaks and ridges. In contrast, low RMR values are measured in outcrops exposing strongly deformed rock masses with strong foliation and/or dense fractures and/or folded structures.

The spatial distribution of the RMR values suggests that low values tend to occur along the edges of major or smaller structural blocks while higher values tend to be found with outcrops inside such structural blocks.

Both high and low strength rock masses are reflected in topography in the form in specific morphological features. To see the tectonic geomorphology the following geomorphological parameters were measured in the study areas: Drainage density; Drainage frequency; Drainage texture; Valley density; Valley frequency. In our opinion high drainage density and frequency together high with valley density and frequency can be associated with low RMR values. While higher RMR values could result in low drainage density and frequency, together with low valley density and frequency.

Not only surface landforms reflect the strength of rock masses and thus the grade of their deformation but subsurface karst features also indicate rock mass strength. Caves especially likely to occur in zones of high structural deformation and thus low rock mass strength. Cave passages seem to follow primary joint systems or major faults based on the comparative analysis of the orientation of more than thirty cave passages and the strike directions of primary joints measured on the surface near the caves.

The authors express their gratitude to Stipendium Hungaricum for the financial support for the research.

Mind versus nature: psychological traps in structural geological research and their reflection in geological maps

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The goal of scientific research, including geology, is to establish objective facts independent of the researcher. Publishing findings and subjecting them to critical review helps ensure objectivity, but since assessments are made by humans, whose thinking is shaped by evolution rather than pure objectivity, biases inevitably arise. As a result, certain perspectives are collectively prioritized, whereas others tend to be overlooked. Tectonic concepts are not exempt from the aforementioned phenomenon. Historians have well documented the evolution of tectonic thinking, from fixism to increasing mobility, though traces of a 'fixism *à la* plate tectonics' mindset remain. However, in this contribution, I focus on more subtle manifestations of these biases, particularly as they appear in geological maps and cross-sections.

One of the most striking tendencies is the depiction of steep boundaries in geological sections. Many novice geologists and students instinctively draw geological boundaries as vertical lines. This issue is also linked to the tendency to overlook longitudinal faults with a dip shallower than stratification, a concept often ignored in classic textbooks, leading to misinterpretations, such as assigning the wrong direction of movement along the fault. A common example is the mistaken identification of dip-slip faults as reverse faults when the dislocation cuts an older thrust structure. The representation of transverse faults is similarly influenced by psychological biases. A typical example is the initial drawing of these faults perpendicular to rock bands on a map, despite this orientation being uncommon in nature. Another recurring issue is the placement of faults along the valley floors, which can also be misleading.

Subhorizontal geological structures in metamorphic and folded terrains pose significant psychological challenges, despite being common and well-accepted in sedimentary settings. The expectation of a finalized geological state fosters the idea of continuous rock structures, leading to the forced interpretation of subhorizontal features within this framework. A notable example is the Czech lens method, which assumes - sometimes with little verification - that a dominant rock type is widespread, with lenses of various rock types appearing only where documented by the geologist.

Although psychological biases often hinder objective knowledge, there are cases where shifts in collective perception have led to breakthroughs in understanding. For example, changes in fashion from the 1960s to the following decade coincided with advancements in retrodeformation techniques for geological cross-sections, accelerating progress in structural geology.

Numerous other instances illustrate how psychological barriers obstruct objectivity, many of which stem from cognitive biases such as anchoring, confirmation bias, and selection bias.

Tectonometamorphic evolution of (U)HT domains in southern Madagascar

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Southern Madagascar consist of Precambrian basement of high-grade rocks with complex history of polyphase deformation and metamorphism. It is typically divided into five lithotectonic domains bounded by faults and shear zones – Ikalamavony, Anosyen, Androyen, Graphite and Vohibory Domains (from SW to NE) that were amalgamated together during the so-called "Pan-African" event. The Ikalamavony, Graphite and Vohibory Domains are interpreted to be the products of intra-oceanic island arc magmatism. By contrast, the Androyen and Anosyen Domains record long crustal histories. The first common event observed in all domains dates to c. 580 – 520 Ma and marks the closure of the Mozambique Ocean. The trace of this suture lies along the boundary between the Androyen and Anosyen Domains and is defined by the Beraketa high-strain zone.

We have performed exploratory field campaign in the Anosyen, Androyen and Ikalamavony domains between the towns of Ihosy and Ampanihy. The Anosyan and Androyen domains here consist of intercalated Neoproterozoic cordierite-garnet-sillimanite pelitic gneisses, calc-silicates and leucocratic gneisses with more abundant quartzofeldspathic gneiss and more common metabasic rocks in the Androyen domain. The Ikalamavony domain composed of metavolcanic and metasedimentary rocks including ocean-floor basalts and mafic to felsic intrusions. Our preliminary field results reveal two types of structural regions – low strain regions associated with open regional folds and high-strain regions (shear zones) with strong, sub-vertical N-S striking foliations that obliterated any previous structures. On a regional scale the large-scale shear zones define limbs of an N-S trending folds, refolding the regional gneissose layering and associated schistosity that we have identified as D_1. The regional N-S fold is thus defined as a D_2 fold. D_1 is marked by subhorizontal shallowly dipping S_1 to the west. The S_1 foliation is folded into kilometric open fold with subhorizontal axis in low-strain domains or completely transposed to a new vertical N-S trending S_2 foliation in high-strain domains, forming vertical high-grade anastomosing shear zone network. These sets of anastomosed shear zones are generally N–S-oriented. All deformation occurred under HT amphibolite to granulite facies conditions as shown by syntectonic melting and migmatization.

Deep structure of the Western Carpathians in southeastern Poland: New insights from integrated geophysical and well data

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Despite over a century of research, the deep structure and evolution of the Western Carpathians remain only partially understood. While surface and shallow geological features are well-documented, deeper structural complexities are still unclear. Recent advancements in geophysical methods have enabled significant progress, yet existing models are often based on isolated datasets or single-method approaches.

This study integrates borehole data with gravity, magnetic, seismic reflection, and seismic refraction data to construct depth maps of key structural horizons in the Outer Carpathians of southeastern Poland. We present new maps of: (1) the crystalline basement, (2) the top of the pre-Miocene autochthonous sediments, and (3) the depth to the Carpathian thrust.

Our analysis of the crystalline basement top reveals two overlapping structural trends: one follows the Carpathian arc and corresponds to a basement depression caused by the load of the overlying thrust nappes, while the other, oriented NNE-SSW, predates Miocene thrusting. The deepest basement depression, representing a cumulative effect of both trends reaches a maximum depth of 24 km.

The top of the pre-Miocene autochthonous sediments dips southward toward the Inner Carpathians due to the loading of the lower plate margin by the Carpathian nappes. The dominant structural trend follows the Carpathian arc, with maximum depressions (7.5 – 8 km below sea level) beneath the axial part of the Outer Carpathians belt. A localized basement high, trending NNE-SSW, is also observed.

The Carpathian thrust exhibits a geometry similar to that of the pre-Miocene basement, with a major depression (>7.5 km below sea level) beneath the axial part of the Outer Carpathians. However, a distinct elevation of the thrust is observed beneath the Magura Nappe along the Slovak border.

Crustal thickness variations highlight the significance of the NNE-SSW structural trend. In the basement depression zone, the crystalline crust thins to 13 km, indicative of strong extension associated with passive margin dynamics and suggesting elevated heat flow in the past. The reduction in crustal thickness parallel to the Carpathian front is less pronounced.

This study provides a comprehensive model of the deep structure of the Outer Western Carpathians in south-eastern Poland, offering new insights into the tectonic processes that have shaped this region.

Employing seismic interpretation for targeting some reservoirs at the Main Abu El-Gharadig oil field, North Western Desert, Egypt by utilizing velocity, inversion models and structural analysis

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The primary goal of the current study is to identify and assess the structural features as well as the hydrocarbon potentialities of the Abu El-Gharadig basin in the Western Desert of Egypt, specifically in the Main Abu El-Gharadig oil field, which is considered to be a part of the Khalda concession and occupies a location in the Abu El-Gharadig basin between latitudes 29°40′ and 29°45′ north and longitudes 28°25′ and 28°32′ east through the integration of different seismic reflection interpretation techniques. The current research focuses on Abu Roash "E" Members of the Abu Roash Formation and Upper Members of the Bahariya Formation, both from the late Cretaceous period. To assess the study area's structural framework and create structure contour maps, twenty 2D seismic profiles were used. Thus, two horizons were selected and interpreted using seismic well ties, which connect seismic data (in the time domain) and well log data (in the depth domain) to produce a synthetic seismogram and a wavelet that is compared to the seismic traces and well location to identify the stratigraphic boundaries of concern. Following that, structure contour maps are created, which show that normal faults trending in the E-W and NW-SE directions have an impact on the entire area. The fault polygons of the four horizons typically show tilted fault blocks with three-way dip closure as well as two-way dip closure creating graben and horst blocks. In order to validate the results obtained, we utilized Post Stack Seismic Inversion to combine seismic and well log data to determine the rocks' physical characteristics. The theory of post-stack seismic inversion has shown itself to be highly helpful in defining the lithology and detecting hydrocarbon accumulations and an obvious lower acoustic impedance anomaly confirmed the presence of hydrocarbons in the area of interest. Moreover, velocity model was created which demonstrates the depositional conditions that is reflected in changing the interval velocity. Also, by superimposing the interval velocity section over the original seismic section, the velocity model QC allows us to determine whether the interval velocity model and seismic reflector correspond well. Finally, we integrated all the methods done in this study to reveal new well proposed locations which may contains commercially hydrocarbon potential.

Alpine zircon in the Variscan granitoid intrusion (Veporic Unit, Western Carpathians, Slovakia): record from close Alpine intrusive overprint?

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The studied area is situated in the Kohút zone which belongs to the Southern part of the Veporic tectonic unit (Inner Western Carpathians, Slovakia). It consists of lower Paleozoic metamorphic rocks intruded by Variscan granitoids covered by Late Paleozoic and Triassic sediments (Plašienka et al., 1997; Hraško et al., 2015). The Alpine (Cretaceous) tectono-metamorphic overprinting in higher greenschist facies medium pressure conditions took place (Putiš, 1994) and Alpine distinct thermal event - re-heating due to the Rochovce granitic intrusion (Plašienka et al., 2007, Janák et al. 2001). The Rochovce granite (Klinec et al., 1980) represents a hidden granitic intrusion on boundary between Veporic and Gemeric units (Hraško et al., 1998; Poller et al., 2001). Till now estimated ages of this intrusion based on zircon U-Pb dating are (e.g.): 82 ± 1 Ma (Hraško et al., 1999), 75.6 ± 1.1 Ma (Poller et al., 2001) and 81.5 ± 0.7 Ma (Kohút et al., 2013). Our new zircon age determination performed in the Korea Ochang SHRIMP laboratory showed age of 84.02 ± 0.07 Ma (MSWD = 2.7) (borehole RO-8, depth 767.6 m).

Alpine granites up to now are unknown from the surface, although many monazites age determinations indicate such situation. Approximately 5 km away from the Rochovce granite intrusion was found on the surface an aplitic granite body (sample HBG-6) showing Variscan age of 357.9 Ma (MSWD = 3.5) with one Late Cretaceous zircon age 82.8 Ma (MSWD = 0.27). The U and Th concentrations in HBG-6 ranged from 107 – 2028 ppm and 31 – 1587 ppm respectively, with Th/U ratios 0.22 – 0.67. Alpine age of 80 Ma in marginal part (1078 ppm U; 389 ppm Th; Th/U = 0.36) and 84 Ma in the core (971 ppm U; 1587 ppm Th; Th/U = 1.63). The value of Th/U ratio 1.63 indicates that it could be fluid formed zircon. This is leucocratic granite to alkali granite reach in K-feldspars and show peraluminous character with A/CNK and A/NK values 1.13 and 1.15, respectively. It is represented by alkali-calcic composition and the sample corresponds to magnesian granitoid rocks like surrounded Variscan granities. The chondrite normalized REE content shows La/Yb = 9 and Eu/Eu* = 0.3. Sample shows an enrichment of Rb, Ba, Th, U, Be and LREE and depletion of Cs, Nb, Ta, Sr, Eu, Zr and HREE relative to the C1 chondrite composition. Cathodoluminescence (CL) images show that most zircon crystals in both samples have clear concentric oscillatory zoning. Data indicate strong fluid mediated overprint of Variscan granite by close Rochovce in quite large distance from the known Rochovce occurrence. Surface finding of Alpine granite is highly probable in this area.

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Vertical extrusion of subducted continental crust: A modeling study for the Rhodope metamorphic complex

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We propose that vertical rise of deeply subducted continental crust into the upper plate's crust (relamination) can happen as extreme events during early collision. We employ 2D thermomechanical modeling of continental subduction/collision using visco-elasto-plastic rheologies and force boundary conditions in order to identify the factors controlling this process.

In our models, upper crust of the passive continental margin is pulled to mantle depth during early collision. Depending on boundary conditions and lithology of the subducting plate, large volumes of subducted buoyant crust can detach from the slab, rise into the upper plate and split the lithosphere even for considerable compressive tectonic stress. At the surface, such an exhumation event is expressed as a phase of intense horizontal extension and magmatism. The process can create a hundreds of kilometers wide core complex, in which metamorphic continental crust derived from the subducting plate is exposed. Depending on boundary conditions such as the horizontal tectonic stress, the thickness of the down-going upper crust and its rheology, the resulting complexes can expose more or less eclogite-facies rocks, be narrow or wide and display high or low topography.

We propose that the Rhodope metamorphic complex (RMC) on the Balkan Peninsula represents a prime example for this kind of dramatic extrusion/relamination internal of the related oceanic suture zone at the surface. The RMC is a wide basement dome to the northeast of the Sava zone. The Sava zone represents the oceanic suture between Adria and Europe that formed about 60 Ma ago after the Vardar ocean had been completely subducted towards northeast below Europe. The lower tectonic units in this domain exhibit Eocene high-pressure metamorphism and nappe stacking followed by massive magmatism and large-offset normal faulting. Despite more than 100 kilometers of extension in Cenozoic times, the area still shows thick crust and high mountains, and we propose that extension was driven by massive vertical extrusion. Our modeling results support schemes that attribute the lower units of the RMC to the Adriatic plate.

Tectonic instability in a supposedly stable region: Paleo-landslides as evidence of past seismicity

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The Outer Western Carpathians (OWC) have long been considered a geologically stable region with low seismic activity. However, emerging geomorphological and structural evidence challenges this assumption, revealing past seismotectonic events that may have gone unrecorded. This study examines paleo-landslides along the Lidečko Fault zone in the Javorníky Mountains (Czech-Slovakian border) as indicators of past seismicity, contributing to a revised understanding of regional tectonic activity.

Through an integrative approach combining high-resolution LiDAR mapping, geophysical imaging of Electrical Resistivity Tomography, paleoseismological trenching, radiometric dating (radiocarbon, OSL), and numerical modeling, we reconstruct the seismotectonic history of the region. LiDAR analysis reveals well-preserved landslide morphologies proximal to Holocene fault ruptures, suggesting a coseismic origin. Structural analyses indicate active strike-slip and oblique-reverse faulting, with surface rupture and liquefaction features supporting earthquake-induced slope failures.

Three distinct generations of landslides have been identified, characterized by depletion zones ~400 m long, 200 m wide, and 25 m deep, with debris runout exceeding 1 km. Radiometric dating of landslide-dammed sediments indicates major events around ~91 ka, 45 ka, and 1.8 ka. To quantify seismic influences, synthetic acceleration data were incorporated into Newmark Displacement Analysis (NDA) and PFC3D numerical modeling, providing insights into the dynamic response of slopes under seismic loading.

Our findings challenge conventional views of the OWC as a seismically inactive region and emphasize the role of landslide archives in reconstructing paleoseismicity. This study underscores the need to integrate structural geology, geomorphology, and neotectonic assessments for a more comprehensive evaluation of seismic hazards in presumed stable regions.

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First U-Pb dating of UHP garnet from coesite-bearing eclogites from the Śnieżnik Massif (NE Bohemian Massif)

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The Orlica-Śnieżnik Dome (OSD), located in the northeastern part of the Bohemian Massif, is interpreted as a fragment of the Moldanubian zone within the Variscan orogen, representing part of the Variscan orogenic root. It is considered a mantled gneiss dome, predominantly composed of orthogneisses interspersed with metamorphosed volcano-sedimentary sequences. In the eastern part of the OSD, within the Śnieżnik Massif, lenses of high- and ultrahigh-pressure (UHP) rocks, including granulites and eclogites, are embedded within the orthogneisses. The metamorphic history of these rocks has been widely debated due to the lack of documented UHP phases. However, our discovery of coesite provides direct evidence that these rocks underwent a UHP metamorphic event, shedding new light on their tectonometamorphic evolution. In this study, we present a detailed petrological analysis of eclogite from Bielice from the OSD, coupled with the first U-Pb dating of UHP garnet from this part of the Bohemian Massif.

The UHP metamorphic event in the studied samples was reconstructed based on the observation of coesite, identified as tiny (~10 – 20 µm) inclusions within omphacite and garnet and the results of thermodynamic modelling, Zr-in-rutile thermometry, and conventional geothermobarometry. The well-preserved mineral assemblage indicative of UHP conditions includes garnet + omphacite + kyanite + rutile + coesite. Phase diagram modeling combined with isopleth geothermobarometry and Zr-in-rutile thermometry indicates peak metamorphic conditions of approximately 3.1 GPa and 800 °C. These results are within the margin of error consistent with the results of conventional geothermobarometry, which indicate slightly higher temperature of ca. 840 °C at pressure of 3.15 GPa.

We used U-Pb dating of garnet to estimate the timing of the UHP metamorphic event. The results obtained for three eclogite samples from Bielice consistently indicate an age of ca. 400 Ma. In this contribution, we explore possible scenarios that could place these results in a geodynamic context of the Variscan orogen.

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Influence of grain size on quartz deformation in pure and general shear experimental setups

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Since quartz is one of the weakest and most abundant mineral phases in continental crust, its mechanical properties largely control the crustal rheology. Understanding its mechanical behavior is crucial for geodynamic models that include crustal strength. Studies on quartz have shown that relatively minor changes in material properties or deformation conditions may largely influence both dynamic and static processes. In this study, we performed deformation experiments on encapsulated powdered samples from crushed single quartz crystal, with the grain size ranges of 1) 64 – 125 µm, 2) 20 – 64 µm and 3) <20 µm. The experiments were performed using the Griggs-type solid-medium apparatus, in both general and pure shear setups, under controlled laboratory conditions of 1 GPa, 900 °C, achieving strain rates of 10×10^{-6} s−1, and with 0.1 wt.% of added H_2O. The EBSD analysis was applied to evaluate the associated post-experimental microstructures, including the determination of active slip systems and the c-axis analysis. The pure shear experiments showed the lowest strength for the largest grain size fraction (~100 MPa), slightly higher for the middle fraction (~150 MPa), and significantly higher for the smallest fraction (~800 MPa). While the resulting microstructures for the largest and middle fraction samples showed pronounced dynamic recrystallization in the hottest parts of the samples (near the thermocouple), the microstructure of the smallest fraction sample showed heterogeneous grain size distribution in form of elongated lenticular zones of finer grain size, preferentially oriented perpendicular to the principal stress σ_1. In several pure shear experiments, the capsule has ruptured at the early stages of deformation. These samples reached differential stresses exceeding or nearly exceeding the Goetze criterion, followed by major cracking and rapid stress decrease, which most likely resulted from the water drainage via the capsule ruptures. Stress-strain curves for the general shear experiments showed gradual but pronounced stress drops after reaching yield stresses, followed by a constant flow stress. Contrary to the pure shear experiments, the smallest grain size fraction in the general shear experiments showed the lowest maximum shear stresses (~150 MPa), while the middle and largest fractions reached ~300 MPa. The pure shear experiments showed c-axis preferentially oriented parallel to the principal stress σ_1, while in the general shear samples c-axis is perpendicular to both σ_1 direction and the grain elongation. The analysis of the misorientation axes showed dominant activity of prism $\langle a \rangle$ slip in both experimental setups and indications for subordinate activity of negative rhomb $\langle a \rangle$ slip in the pure shear samples. An unusual recovery microstructure was observed in one of the hot-pressed samples with the largest grain size, where a pronounced grain growth took place in the hottest parts of the sample. The resulting average grain size after the growth was considerably smaller compared to the larger clasts in the initial microstructure, which suggests that the recovery microstructure was developed by medium-sized grains growing at the expense of both smaller and larger grains.

Exhumation of the western part of the Sava suture zone: Insights from Zrinska Gora (Croatia)

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The Sava Suture Zone (SSZ) marks the tectonic boundary between tectonostratigraphic units derived from the Adria and European plates. The final closure of the Neotethys ocean during the Late Cretaceous and Paleogene led to nappe stacking and formation of syntectonic basins concentrated along and in the SSZ. Outcrops of the SSZ and foreland basin sediments are rare, being mostly widespread in the northern Bosnia and Herzegovina. This study focuses on the Zrinska Gora (Central Croatia), an inselberg located in the western part of the SSZ, northwest of the Kozara and Prosara mountains. Zrinska Gora mostly exposes foreland basin deposits - Maastrichtian to Paleocene turbidites and Eocene shallow-water to continental coarse clastics which overlay Campanian Scaglia type limestones. In the eastern part of Zrinska Gora, a rock complex typical for the SSZ can be found: Campanian sediments, mostly carbonates and clastics with turbiditic characteristics, and mafic magmatic rocks.

Here we present new apatite (U-Th)/He ages and organic maturation data from both units. In the Upper Cretaceous to Eocene shale the vitrinite reflectance values are mainly consistent and are in the range from 1.07 to 1.46 % regardless of stratigraphic age. Considering the duration of the potential effecting heating time it indicates that the burial temperature was around 120 °C. Apatite grains from Upper Cretaceous to Eocene sandstones were used for thermochronological analysis. Acquired (U-Th)/He ages are younger than stratigraphic ages confirming the reset of the apatite He-thermochronometer in both units. The detected reset is in accordance with the maximum burial temperature that was deduced from the organic maturation analyses. The age data suggest that the exhumation climaxed during early period of Pannonian Basin formation. Also, several exhumation subphases can be identified within the Zrinska Gora area. The first initial exhumation subphase is dated to around 38 Ma and could be associated with nappe stacking and cogenetic tectonic erosion. These ages are recorded within Lower Paleocene sandstones of the foreland unit, which suggests rapid burial followed by fast tectonic erosion and exhumation in the Paleogene. The second subphase represent principal exhumation, with an average age of 21 Ma, which caused tectonic uplift of both units of the wider area of Zrinska Gora. The third and the last recorded subphase is dated around 9 Ma and may constrain cooling after Sarmatian localized tectonic inversion of the Pannonian basin.

Ediacaran metagranite from the northern Veporic zone: A record of long-lasting magmatic and metamorphic evolution

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Variety of rocks is found in the basement in the northern Veporic zone, which typically lacks large Variscan granitoid plutons. The rock types include orthogneiss, metagranite, eclogite, ultramafite and metapelite. All these rock types experienced high pressure Variscan metamorphism (Janák et al. 2007, 2020, Petrík et al. 2020, 2024) reaching pressures up to 22 – 24 kbar and temperature up to 650 °C. Being rich in monazite the metagranite and metapelite were dated by Th-U-Pb chemical method (Petrík et al. 2020, 2024). Although the dominant age in both rock types is Ordovician (460 – 480 Ma) indicating Cenerian metamorphism, monazites record a long history including 520 – 584 Ma old cores and Variscan (350 – 360 Ma) rims. Low-Ca orthogneisses record also a low temperature Alpine overprint (96 Ma). All these monazites are interpreted as metamorphic; therefore, a magmatic age is presumably preserved by zircons. Metagranite zircons separated from heavy fraction were dated by high resolution ion probe (LA-ICP-MS) at the Korea Basic Science Institute in Ochang. Zircons (100 – 200 µm across) show mostly oscillatory zoning in CL, with some distinct cores. BSE images of several crystals show bright thin annuli enriched in U.

The results yielded three Paleoproterozoic cores/rims (2181 – 1912 Ma), four Tonian cores (987 – 783 Ma), seven Cryogenian/Ediacaran cores/rims (664 – 602 Ma), and two Ordovician rims (480 – 459 Ma). No Variscan age was detected. The most abundant Ediacaran points have relatively constant Th/U ratios ca. 0.67 indicative of magmatic origin. If true then the metagranite magmatic age is Ediacaran (Cadomian) and the rock has a Gondwanan provenience. The younger ages indicate Cambrian and Ordovician metamorphic reworking as recorded also by monazite.

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The Western Carpathians: a polycyclic Meso-Cenozoic orogen

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As a plate-tectonic paradigm, the classic Wilsonian cycle comprises a succession of large-scale processes, such as continental rifting, breakup, formation of passive margins, oceanic spreading, passive to active margin conversion, subduction of the oceanic lithosphere and, after its consumption, the ensuing continental collision. These processes are regularly recorded in many ancient collisional orogens worldwide which involve oceanic sutures with ophiolite and/or HP/LT metamorphic units and associated synorogenic accretionary/mélange complexes. The sutures separate former lower-plate passive and upper-plate active margins recording different tectonic, magmatic and sedimentary evolution. However, several Alpine-type orogens, including the Western Carpathians (WeCa), embrace more than one suture-like zones that are characterized by at least one of these fundamental criteria.

The Alpidic tectonic evolution of the WeCa embraced a time span of about 245 Myr from the continental breakup and opening of the Meliata Ocean, up to the recent final docking and relaxation of the WeCa orogenic wedge. The continuing, though episodic orogenic convergence itself commenced not later than at about 180 Ma ago. Based on the above criteria, the entire WeCa orogenic story may be subdivided into three partial Wilson-type cycles: 1) the Tethyan cycle was related to the opening, subduction and suturing of the Meliata Ocean (time range ca 245 – 150 Ma); 2) the Palaeo-Alpine cycle commenced by opening of the Váh oceanic branch of the Alpine Atlantic and lasted until its closure (roughly 170 – 70 Ma); 3) the Meso-Alpine cycle began by onset of the Magura Ocean spreading and terminated by its complete subduction (130 – 20 Ma). Accordingly, these three partial cycles were overlapping in time and space and each of them lasted for about 100 Myr, which resulted in an exceptionally complicated tectonic scenario for evolution of the entire WeCa orogen and its parts. The concluding Neo-Alpine period took the last 20 Myr and was related to the final frontal thrusting of the accretionary wedge overriding the foreland European plate, simultaneously with the extensional breakdown of the core of the WeCa orogenic system.

It is disputable, whether or not yet another, the Austroalpine (or Eo-Alpine) partial cycle could be distinguished. It is registered by rifting (200 – 190 Ma) of the intracontinental Fatric basin with an attenuated, later entirely subducted/underthrust crust during the period from ca 110 Ma to 90 Ma until the final collision of its lower-plate Tatric and upper-plate Veporic margins. In view of that, this rifting–collision cycle would embrace the time span of roughly 100 Myr, too.

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The specific crystallographic and microstructural aspects of coesite to quartz phase transition during the initial stage of UHP rocks recrystallization (Dora Maira, Western Alps)

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Silica (SiO_2) constitutes one of the most important components of the geological environment. One of SiO_2 polymorphs called coesite forms under ultra-high pressure (UHP) metamorphic conditions and represents a significant indicator of extreme conditions in tectonically active zones. Nevertheless, its presence is scarce in the exposed rock formations due to its inherent instability and tendency for immediate recrystallization to quartz. This study investigated the relationships, similarities, and differences of the aforementioned SiO_2 polymorphs in the Dora Maira white schists (Western Alps). The investigation was carried out through microstructural observations, electron backscatter diffraction (EBSD), cathodoluminescence (CL), and scanning acoustic microscopy (SAM). Quartz manifests as the main matrix mineral and as common inclusions within garnet. Coesite is identified as inclusions (up to 2 mm) within garnet porphyroblasts as well as grains outside garnet. It is invariably surrounded by quartz. Our observations allow us to distinguish the three distinct microstructural stages of crystallographic non-preferred oriented quartz. (1) The first generation of palisade quartz (PQ1) forms a thin rim composed of narrow (0.005 to 0.1 mm wide) and perpendicularly aligned quartz crystals in two distinct positions: around a coesite inclusion in contact with surrounding garnet and as a thin rim sharply separating outer garnet PQ1 rim. Another microstructure represents the (2) second generation of palisade quartz (PQ2). The bigger grains PQ2 (0.2 – 1.5 mm) are dominated by the sub-grain rotation (SGR) and grain boundary migration (GBM) recrystallization mechanism. The result of this process over time was the (3) complete recrystallisation of the matrix quartz (MQ) with polygonal texture, clearly defined sharp grain boundaries, and uniform grain size (0.1 to 0.5 mm). The CL images of the various quartz microstructures display homogenous patterns. On the other hand, CL is an easy and straightforward method for identifying or verifying the presence of coesite in our samples. Coesite is significantly brighter and distinguishable from surrounding minerals. The issue lies in the fact that this method is rather time-dependent, and after a brief period, the coesite extinguishes and becomes indistinguishable from quartz. It is reasonable to hypothesize that the marked luminosity, and its temporal limitation, are associated with the elevated defect density of coesite crystallographic structure during the process of its formation. The SAM method was instrumental in documenting these differences for the first time. The method revealed that quartz and coesite exhibit distinct acoustic properties. Furthermore, it was observed that these differences in acoustic properties are also present among different quartz microstructures. It should be noted, however, that this aspect of the study is still in the calibration phase and requires further data to be fully validated.

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Stability of jadeite in UHP metamorphosed felsic rocks, example from the Bohemian Massif

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Experiments and thermodynamic modeling suggest that jadeite-rich clinopyroxene should be stable in quartzofeldspathic rocks subjected to (U)HP metamorphism. However, natural occurrences of jadeite are exceptionally rare, even when UHP conditions are confirmed by index minerals such as coesite or diamond. This discrepancy may result from either its complete consumption during exhumation or its absence during HP metamorphism. The latter possibility could be attributed to fluid deficiency or the overstepping of the clinopyroxene-in reaction under HP conditions.

In this contribution, we examine a felsic meta-igneous rock from the Erzgebirge Mts. (Bohemian Massif) composed of garnet, kyanite, phengite, quartz, K-feldspar, and plagioclase. The presence of coesite relics within garnet confirms UHP metamorphic conditions. The matrix contains fine-grained symplectites of albite and muscovite, occasionally accompanied by garnet. Similar textures were previously interpreted as pseudomorphs after jadeite (Massonne, 2024) although in contrast to their work, our samples revealed several jadeite inclusions in kyanite and garnet. The averaged composition of the albite-muscovite symplectite closely matches that of jadeite, apart from Na depletion and K enrichment.

Two generations of garnet were identified. The first generation (Grt 1), forming the majority of large crystals, is almandine-rich, with decreasing Ca and Fe and increasing Mg toward the rim. It also exhibits Na and P enrichment from the core, followed by a sharp decrease at the rim, where a jadeite inclusion was found. The second generation (Grt 2) is Ca-rich and Na-P-poor, occurring at the outermost rims of large crystals and as small grains within the albite-muscovite clusters. Our observations document peak conditions within the coesite stability field, characterized by the mineral assemblage Grt-Jd-Ky-Ms-Coe-Kfs. This stage was followed by partial decompression outside of the coesite stability but still within the jadeite stability (indicated by jadeite inclusion in P-poor garnet rim). The final phase involved the breakdown of jadeite into albite and muscovite, leading to Ca enrichment in the garnet rims.

Our study reveals a correlation between experimental results and natural samples subjected to UHP conditions, confirming the presence of jadeite in felsic rocks under HP conditions. However, jadeite appears to disappear efficiently during decompression.

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Variscan orogeny: a three oceans problem

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The Variscan orogeny resulted from opening and closure of the Rheic Ocean and its successor Rhenohercynian and Paleotethys oceans. The subduction of Rheic Ocean started in late Silurian along Laurussia and in mid-Devonian along Gondwana. Devonian roll-back of peri-Laurentian Rheic subduction led to growth of the Rhenohercynian Ocean contemporaneously with multiple peri-Gondwanan subductions. Further east, mid Devonian Rheic subduction beneath Gondwana resulted in opening of wedge-shaped Paleotethys Ocean and separation of the Galatian peninsula. Carboniferous spreading of Paleotethys led to closure of remaining Rheic oceanic domains, welding of Gondwana derived blocks into Variscan Collage that collided with Laurussia. The subduction was located in the northern Paleotethys margin and resulted in massive extension and melting of the Variscan Collage. These processes are related to final stages of Pangea formation and cannot be explained using standard geodynamic scenarios of subduction followed by collision routinely applied to Himalaya and Alpine collisional systems. The whole evolution of the interior Pangean realm has to be seen as a domain that suffered recurrent closure and opening of oceanic domains. The paleogeographic reconstructions show permanent presence of vast oceanic domains between Laurussia and Gondwana in the region of future Variscan belt during Paleozoic times. This is not however applicable for the Appalachian and Mauritanian Rheic tract that was continuously shrinking from 420 to 330 Ma. This implies a presence of permanent spreading region in the core of future Pangea responsible for semi-continuous Wilson cycles marked by sequentional origin and closure of oceans. This kind of behaviour is very unusual and cannot be explained by a scenario in which one long lasting subduction drives the Variscan orogenic cycle as proposed in classic scenarios. Instead, it can be speculated that the rapid fluctuations of spreading centres and subduction systems may result from major mantle upwelling in the core of the future Pangea.

Tectonostratigraphy of the southeastern part of the Bohemian Massif

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Ophiolites and eclogite bearing units are important to reveal the tectonostratigraphy of orogenic belts as they define the position of suture zones. Especially an oceanic suture is a significant tectonic element as it separates former continental entities, which might have been far away from each other before oceanic closure and the subsequent continental collision. Conversely, the tectonic subdivision of an orogen should always reflect the former palaeogeographic relationships so that the 1st order tectonic units can be defined in a comprehensible manner.

In the southeastern part of the Bohemian Massif, ophiolite slices and eclogite occurrences are known since several decades. They are likely remnants of the oceanic space (Proto-Rheic and/or Rheic oceanic domain) that separated peri-Baltic (e.g. Avalonia) and peri-African (e.g. Armorican) crustal elements before the Variscan collisional event. However, due to a post nappe-stacking metamorphic overprint reaching granulite facies and anatexis many shear zones responsible for nappe stacking are strongly recrystallized and now difficult to identify.

The tectonic nomenclature most commonly used to this day dates from 1927. It divides the area into the low-grade to amphibolite facies Moravicum and the granulite facies Moldanubicum. The Moravicum is the southwestern continuation of the Brunovistulicum, which also includes parts of the Variscan foreland. In addition, the late-/post-collisional South Bohemian Batholith is distinguished and the strongly anatectic Bavaricum in the southwest is optionally separated.

In the course of detailed mapping in the Danube valley, former peri-Baltic and peri-African rock units as well as an intervening oceanic suture zone were separated based on lithological criteria. This subdivision can be tentatively extrapolated to the entire southeastern part of the Bohemian Massif. In general, a southwest-northeast orientated oceanic suture separates peri-Baltic derived units form the footwall in the East, and peri-African derived units in the West. However, the tectonic style is complex with flower structures and out of sequence thrusts.

The presently used terminology only partially reflects these palaeogeographical aspects. The peri-Baltic units build up the Moravicum, but also the Drosendorf Nappe System of the Moldanubicum. The ophiolites of the oceanic suture zone are part of the Gföhl Nappe System and the eclogites occur in the easternmost part of the Ostrong Nappe System. Both these nappe systems belong to the Moldanubicum according to the classic nomenclature. The remaining Moldanubicum most probably originates from Armorica, i.e., the African sector of Gondwana. In order to create a more logical nomenclature we suggest to use the term Moldanubian Unit exclusively for rock units derived from the African sector of the Gondwana margin. The oceanic suture zone could be included in a separate 1st order unit (Raabs Unit). Nappes that consist of peri-Baltic rocks like the Drosendorf Nappe System should be affiliated with the Moravian and Brunovistulian units, whereas the Variscan foreland might be treated separately.

Integrated remote sensing and geophysical approaches for delineating structural controls on radioactive mineralizations: A case study from the Central Eastern Desert, Egypt

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El-Missikat and El-Erediya areas within Egypt's Central Eastern Desert are renowned for their substantial potential in radioactive mineralizations. Primarily owing to the prevalence of extensive shear zones within the syenogranitoid plutons. The radioactive mineralizations in these terrains are predominantly structure-controlled, as mineral concentrations are intricately localized along these tectonically induced shear zones. The paramount objective of this research is to synergistically integrate remote sensing data from Sentinel-2 and PRISMA with airborne geophysical methodologies, encompassing magnetic and radiometric information, to precisely delineate the structural frameworks governing the spatial distribution of radioactive mineralizations. These structures, encompassing shear zones, fault systems, dykes, and joint networks, play a pivotal role in channeling mineralizing hydrothermal fluids, thereby influencing ore deposition and localization. To achieve this objective, satellite imagery underwent rigorous processing utilizing an array of advanced analytical techniques, including false color composites, principal, independent component analyses, minimum noise fraction and band ratios. For geophysical data, quite a few enhancement filters (maps) under the terms of tilt angle derivative (TD), and Euler deconvolution (CET) grid analysis, were applied to the Reduced to pole (RTP) aeromagnetic grid. Our findings meticulously delineated the distribution of shear zones across the study area. These tectonic discontinuities traverse the (N) sector of the El-Missikat and El-Maghrabiya plutons while exhibiting a pronounced presence in the (S) domain of the El-Erediya pluton. Beyond structural mapping, our results unveiled an extensive network of felsite, aplite, and lamprophyric intrusions, along with oriented NE–SW quartz-feldspar porphyry dykes. Moreover, airborne geophysical investigations have unveiled intricate structures confirming that the majority of detected automated lineaments exhibit a dominant NW orientation. This structural trend is regarded as the principal tectonic control governing the localization and distribution of mineralization within the region. This integration is further reinforced through comprehensive field investigations, providing crucial ground validation for interpretations. Therefore, we strongly advocate for the fusion of these datasets in future explorations to precisely delineate the structural frameworks governing mineralization processes.

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Tectonic and geomorphological conditions of small lakes development at the southern margin of the Arts Bogd massif (Govi Altai Range, Mongolia)

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The interpretation of the genesis and evolution of lake reservoirs provides insights into the dynamics of mountainous landscape development in Mongolia. Many lakes in the region are of tectonic origin. Our analyses show that this is a major factor influencing the location of the small lakes we studied along the southern edge of the Arts Bogd massif in the Gobi Altai Range. Tectonically, the Gobi-Altai Range is classified as an intraplate, intracontinental transpressional orogen within which it has been recognized a complex structure known as restraining bend mountain range. It extends approximately 300 km along the latitudinally oriented (WNW-ESE) Bogd Fault System (Cunningham 2007, 2010, 2013).

The pronounced influence of bedrock tectonics on the relief dictates the latitudinal orientation of mountain massifs and the formation of endorheic intramontane basins, shaping the regional drainage network. The studied dried-up lake reservoirs are elongated and aligned in a W-E direction within a zone marking a regional shift in slope orientation, parallel to the regional strike-slip faults south of the Arts Bogd massif. Our analyses suggest that this zone represents a segment of a larger structure running obliquely between the Bogd Deforming Belt and the Gobi–Tien–Shan Deforming Belt (Cunningham 2007, 2010, 2013). It is the axis connecting the Shereegeen Gashoon basin with adjacent basins to the southwest and northeast (e.g. Ulaan Nuur basin).

Topographic and structural analyses indicate that the intramontane basins along this axis likely formed due to lithospheric stretching between sinistral strike-slip fault zones. These large-scale, currently active en-echelon structures have been evolving since at least the Late Cretaceous, leading to the formation of a pull-apart basin system. Additionally, the latitudinal alignment of terrain features appears to enhance aeolian processes driven by WNW-ESE winds (Westerlies), which contribute to the formation of deflation basins. Our results suggest that aeolian activity represents a secondary but significant factor influencing the development and morphology of lake basins in the study area.

Isothermal compression of an eclogite from the Western Gneiss Region (Norway)

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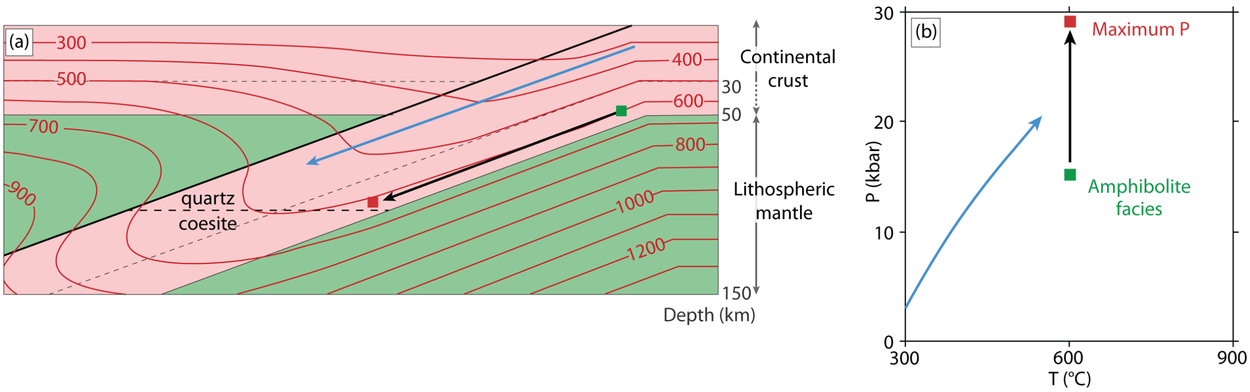
In the Western Gneiss Region in Norway, mafic eclogites form lenses within granitoid orthogneisses and contain the best record of the pressure and temperature evolution of this ultrahigh-pressure (UHP) terrane. Their exhumation from the UHP conditions has been extensively studied, but their prograde evolution has been rarely quantified although it represents a key constraint for the tectonic history of this area. A well-preserved phengite-bearing eclogite sample from the Nordfjord region was investigated using phase-equilibrium modelling, trace-element analyses of garnet, trace- and major-element thermo-barometry and quartz-in-garnet barometry by Raman spectroscopy. Inclusions in garnet core point to crystallisation conditions in the amphibolite facies at 510 – 600 °C and 11 – 16 kbar, while chemical zoning in garnet suggests growth during isothermal compression up to the peak pressure of 28 kbar at 600 °C, followed by near-isobaric heating to 660 – 680 °C. Near-isothermal decompression to 10 – 14 kbar is recorded in fine-grained clinopyroxene-amphibole-plagioclase symplectites. The absence of a temperature increase during compression seems incompatible with the classic view of crystallization along a geothermal gradient in a subduction zone and may question the tectonic significance of eclogite-facies metamorphism. Two end-member tectonic scenarios are proposed to explain such an isothermal compression: (1) either the mafic rocks were originally at depth within the lower crust and were consecutively buried along the isothermal portion of the subducting slab, or (2) the mafic rocks recorded up to 14 kbar of tectonic overpressure at constant depth and temperature during the collisional stage of the orogeny. The first scenario is rarely evoked. Yet, it presents an attractive alternative and similar P–T evolutions could be much more widespread than reported so far.



Ancient magmatic basement of the Bohemian Massif as a possible paleogeographic tracer

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The pre-collisional paleogeography of crustal blocks involved in the Variscan collage remains a matter of debate. Large parts of the Variscan Belt, including most of the Bohemian Massif, are believed to be of West African origin. A key piece of evidence quoted in paleogeographic reconstructions is the absence of Mesoproterozoic detrital or inherited zircons, considered to reflect a long-lasting magmatic lull in the West African Craton during the Mesoproterozoic. Besides the detrital provenance analysis, though, it is essential to study the oldest igneous complexes that may directly represent relics of the original cratonic basement.

To address this task, the pre-Ediacaran magmatic record in the Variscan orogenic root (Moldanubian Zone of the Bohemian Massif) was studied using U–Pb zircon ages, zircon Hf isotopic as well as whole-rock geochemical and Sr–Nd isotopic data from scattered, rare fragments of metaigneous rocks hosted by the high-grade metasedimentary Varied Group. Our results confirm the presence of already known Paleoproterozoic (c. 2.08 Ga) qtz dioritic–granitic orthogneisses but also newly reveal Mesoproterozoic (c. 1.27 Ga) felsic orthogneisses and metabasic rocks. Based on the whole-rock geochemistry, two-stage Nd model ages (T_{DM}^{Nd} = 1.82 to 2.90 Ga) and zircon Hf isotopic data ($\varepsilon Hf_{(t)}$ = −4 to +11), the older suite formed both from CHUR-like mantle-derived magmas and by partial melting of the older continental crust. The younger bimodal magmatism (T_{DM}^{Nd} = 1.11 to 1.81 Ga; $\varepsilon Hf_{(t)}$ = +2 to +13) represents a combination of EMORB-like, depleted mantle- and juvenile crust-derived components.

The Paleoproterozoic magmatic event is interpreted as a result of slab failure during amalgamation of the Columbia supercontinent and the Mesoproterozoic event is linked to an intracontinental rifting during its break-up. The presence of the newly detected Mesoproterozoic (c. 1.3 Ga) magmatic record challenges the generally accepted primary relationship of the Moldanubian Zone of the Bohemian Massif with the West African Craton. While the c. 2.1 Ga magmatism has been documented worldwide, the c. 1.3 Ga anorogenic magmatic complexes are generally rare. They are typical of the southwestern Baltica and western Amazonian Craton situated at that time along the western margin of Columbia. It implies a possible alternative Precambrian paleogeography of the core of the Bohemian Massif and, potentially, also other parts of the Variscan belt.

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New petrochronological and metamorphic constraints on the early Paleozoic tectono-thermal evolution of the Alashan block (NW China)

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The Alashan block is connecting the Central Asian Orogenic Belt in the north to the Proto-Tethyan domains in the south. Numerous studies of magmatic rocks revealed the existence of a long-lasting tectono-thermal evolution in the Alashan block in the early Paleozoic. However, available metamorphic constraints on these tectono-thermal events remain comparatively scarce. In order to address this issue, we performed petrochronological and metamorphic studies of amphibolites and their host aluminum-rich metapelites from the Langshan belt in the western Alashan block. In metapelite, inclusions of tourmaline and titanite in garnet as well as relics of staurolite in the matrix represent rare vestiges of prograde M_1 metamorphism. Peak M_2 metamorphism is characterized by the Grt–Ms–Bt–Ky–Pl–Qz–Rt and Grt–Bt–Sil–Pl–Qz–Ilm mineral assemblages, whereas retrograde M_3 metamorphism is characterized by the And–Ms–Pl–Qz–Chl–Ilm assemblage. In amphibolite, peak M_2 metamorphism is represented by the Grt–Hbl–Pl–Qz–Rt±Ttn assemblage whereas the crystallization of Amp–Pl–Bt symplectites after garnet reflects retrogression during M_3. Phase equilibria calculations for amphibolite are used to constrain peak M_2 and retrograde M_3 metamorphic stages at P–T conditions of 9 – 11.5 kbar and 780 – 810 °C and ~4.5 kbar and 540 °C, respectively. Metapelites are characterized by a clockwise P–T path with prograde, peak and retrograde metamorphic stages constrained at ~5 kbar and 525 °C (M_1), 7 – 8 kbar and 670 – 720 °C (M_2) and 3 – 4 kbar and 500 – 550 °C (M_3). Zircon and texturally-controlled monazite U–Pb dating of amphibolite and metapelite samples yield complex Ordovician to Devonian age datasets, with metamorphic dates characterized by low $(Yb/Gd)_N$ ratios ranging 469 – 389 Ma. Garnet Lu–Hf dating of amphibolite yield two fairly consistent isochron ages of 425.8 ± 4.2 Ma (MSWD=2.6) and 421.9 ± 7.3 Ma (MSWD=10.4). The preferential distribution of Lu in garnet core suggest that these ages reflect prograde M_1 metamorphism. In contrast, garnet Lu–Hf and Sm–Nd dating of metapelite yield isochron ages of 396 ± 12 Ma (MSWD=4.3) and 387.3 ± 8.0 Ma (MSWD=9.2), respectively. Based on the preferential distribution of Lu in garnet mantle and the absence of zoning in Sm and Nd, these ages are tentatively interpreted as reflecting peak M_2 metamorphism and early stages of cooling during M_3 retrogression. Combined with the available regional data, this study reveals the existence of a protracted metamorphic evolution for the Alashan block in early Paleozoic initiated at 426 – 422 Ma with rock burial related to crustal thickening of a supra-subduction active margin concomitant with extensive magmatic input. This constrictional event operated until ca. 400 Ma and was followed by cooling during exhumation after ca. 390 Ma. The duration and timing of these tectono-thermal events are comparable to those of the neighboring Dunhuang block, suggesting that the Tarim-North China collage recorded a major orogenic event related to its construction in the early Paleozoic.

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Deep crustal structure of the tectonic contact between Europe and ALCAPA in the Western Carpathians revealed by Receiver Function analysis

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The tectonic boundary between northern Europe and the Alps-Carpathian-Pannonian (ALCAPA) crustal blocks in the Western Carpathians remains a subject of ongoing debate and extensive study. On the surface, this contact is marked by the Pieniny Klippen Belt (PKB), a ~600 km long and a few kilometers wide zone characterized by limestone klippens embedded in a flysch matrix, forming a distinct "block-in-matrix" structure. These sediments, deposited in a shallow marine environment, have led to the hypotheses that they originated on a Briançonnais-like continental block—the Czorsztyn Ridge—within the Alpine-Tethys Ocean. It is proposed that this ridge, along with the Vahic oceanic crust, subducted beneath the Tatric thrust sheet.

To investigate the deep structure of this contact, we conducted a passive seismic experiment utilizing Receiver Function (RF) analysis. RFs, derived from teleseismic wave interactions with subsurface structures, enable imaging of deep geological features along seismic transects. Our study involved deploying 18 seismic stations along a north-south profile across the Western Carpathians, supplementing data from nine pre-existing stations.

Common Conversion Point (CCP) imaging of the RF data reveals no evidence of a distinct crustal block wedged between the Tatric nappe, separate from either the European crust or ALCAPA. Instead, the findings suggest that European crust extends further south than previously thought. Additionally, the results indicate basement involvement in the frontal nappes of the Magura and Silesian units. The receiver functions also indicate a distinct Moho at ~30 km depth, while its apparent absence beneath the PKB may correspond to a Moho step associated with the Europe-ALCAPA collision. Distinct crustal fabrics further differentiate the European and ALCAPA domains.

Further integration of these results with potential field studies will enhance our understanding of the structure and tectonic evolution of this complex and debated boundary.

Self-limited nature of interstitial convection in crystal mushes as a novel mechanism of melt differentiation and cumulate formation

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The processes of igneous differentiation, related crystal-liquid separation, and formation of igneous cumulates has been of paramount importance for igneous petrology for over a century. While co-responsible for creation of a diversity of igneous products and Earth's internal structure itself, and thoroughly documented by vast amount of geochemical data, the physical mechanisms of differentiation processes remain poorly understood. The proposed end-member physical scenarios include: (i) separation of crystals from melt via, e.g., gravitational settling and formation of a redistributional cumulate; and (ii) formation of cumulates in-situ, facilitated by crystallization from melt percolating through a partially crystallized solid framework.

In this contribution, we employ three-dimensional numerical models of crystallization by nucleation and growth of crystals to explore the nature of liquid percolation through the solid framework. As crystallization progresses, the interconnected framework forms at ~30 – 50 vol.% of crystals; with specific crystallinity value being sensitive to crystal shape. At this threshold, melt percolation within the framework may start, driven by either melt buoyancy or external forces. However, according to the crystallization models, significant volume fraction of a total crystal content (~8 vol.% at the crystallinity of 30 vol.% is not connected to the solid framework. These effectively suspended crystals are advected with the melt as it flows through the interstitial spaces and are deposited at small-enough pore spaces, where they cannot fit through. As a result, crystal framework clogs and its porosity and permeability drops, rendering melt percolation a self-limited process. While limiting the melt flow, the proposed "clogging mechanism" enables in-situ formation of cumulate by local redeposition of suspended crystals.

The simulations show that crystal content of up to ~85 vol.% may efficiently be reached by clogging, potentially forming almost a monomineralic cumulate. For realistic scenarios, this can be achieved with a melt/rock volumetric ratio of ~5. Simple melt flow calculations show that, in mafic melts, such an effect is possible within hundreds of years, rendering the clogging an effective melt differentiation and cumulate formation mechanism.

Late Quaternary activity of Mariánské Lázně fault and its complexity (Cheb Basin, Bohemian Massif)

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We conducted a paleoseismic study at the Kopanina site along the NNW-SSE trending Mariánské Lázně Fault (MLF), situated in the western Bohemian Massif, Czech Republic. The MLF is a morphologically distinct fault that controls the eastern boundary of the Cheb-Domažlice Graben over a length of 100 km. In its northern portion, the MLF intersects the NE-trending Cenozoic Eger Rift in the area of the Cheb basin. The Cheb Basin is a region characterized by mid-Pleistocene volcanism, mantle-derived CO_2 emanations, and present-day earthquake swarms (Mw ≤ 4.0) that are aligned along a NNW-trending fault. While the MLF does not exhibit contemporary seismicity, our study reveals evidence of Late Quaternary and even Holocene surface-rupturing earthquakes that have shaped the current landscape, with the youngest one dated to around 11th century AD.

To investigate past seismic activity further, we employed 3D trenching and geophysical surveys at the Kopanina site to assess fault zone characteristics and horizontal displacements associated with inferred strike-slip kinematics. We excavated seven backhoe trenches and six hand-dug micro-trenches, exposing a complex structure with Late Quaternary deformation. Geophysical surveys, including 3D ground-penetrating radar (GPR), dipole electromagnetic (DEMP) mapping, and 2D and pseudo-3D electrical resistivity tomography (ERT), provided a detailed image of subsurface structures. The trenching and geophysical techniques revealed horizontally offset sedimentary bodies, with larger-scale displacements captured by geophysics and finer-scale offsets detected through trenching. This combined survey revealed the MLF at the Kopanina site to have a complex structural configuration of oblique faulting and deformation linked to Late Quaternary right-lateral transpression.

The combination of 3D trenching and 3D geophysics proved highly effective in characterizing the fault structure and kinematics, especially in strike-slip regimes. Our findings confirm Pleistocene to Holocene surface-breaking earthquakes along the MLF, providing new insights into the region's seismotectonic history and emphasizing the need for continued investigation of its seismic potential.

Melt-mediated coupled dissolution-precipitation (MM-CDP) of zircon - a new mechanism of zircon modification in metagranite

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In zircon, transgressive textures across the oscillatory zoning and associated chemical modifications were mostly attributed to the process of fluid-mediated CDP over the past c. 20 years. Some works admitted a possible role of melt in zircon CDP, expressing it for example by "fluid/melt", but usually without explicit melt presence documentation. The role of melt in certain zircon textures formation has been considered, but not in the context of MM-CDP. Instead, zircon dissolution into melt, followed by growth of new zircon occurring at different time and location from the dissolution was expected. The studies of zircon modification by MM-CDP are thus extremely rare. Here, we focus on modification of zircon on the example of one of the most common crustal rock types, a meta-granite, which undergone migmatization from eclogite- to amphibolite-facies in the Snieznik dome, Bohemian Massif.

The principle of CDP is that a fluid/melt causes dissolution of a phase and more stable phase(s) subsequently nucleate on the parent surface. Propagation of the replacement front is possible if pathways connect the interface fluid with the bulk fluid. This is achieved through porosity formed as a consequence of volume deficit. Typical texture of CDP is thus presence of porosity, eventually filled with fluid/melt or secondary inclusions, and secondary transgressive textures across primary zoning. We show that most of the secondary textures are not visible in CL, so combination with high-resolution BSE and SE images is necessary. Oscillatory zoning is commonly blurred and in places truncated by patchy or structureless embayments. The irregular boundaries of the embayments are in places spatially associated with micro-porosity, and are interpreted as modification fronts. Micro-porosity and inclusions arranged in trails along modified channels show that CDP may be very focused. Some modification fronts are superimposed indicating that several pulses of CDP affected the crystals over time. These textures show that CDP is a dynamic process affecting crystals at various scales, during which P–T and bulk melt composition may evolve, and zircon may have not necessarily achieved equilibrium with bulk melt. MM-CDP leads to pronounced modification of trace and rare earth elements, and produces smears of mostly concordant dates along Concordia. Care should be taken in choosing analytical spots, and in interpretation of the dates from zircon affected by MM-CDP. In the studied case the oscillatory zoned domains with 540 – 580 Ma ages are interpreted as xenocrysts and c. 500 Ma as magmatic protolith, in agreement with previous studies. It is not clear whether the smear of dates from BSE-homogeneous domains from c. 375 to c. 330 Ma reflects duration of migmatization passing from eclogite to amphibolite-facies, or incomplete zircon modification.

Tracing faults: From LiDAR pixels to outcrops – resolving the structural complexity of the Bystre thrust-sheet (Outer Carpathians, Poland)

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Understanding fault networks is crucial for various geological applications, including the exploration of natural resources, the assessment of geohazards, and the interpretation and reconstruction of geological history. The Bystre Thrust-Sheet, located within the Fore-Dukla Zone, is a key tectonic feature separating the Silesian and Dukla Nappes in the Outer Carpathians. The area exhibits a complex structural setting, including poorly understood fault systems, making it a valuable site for advanced structural geology research and tectonic analysis.

Structural analysis based on LiDAR data revealed faults that record NE-SW-oriented shortening, as well as additional shortening directions of approximately N-S and E-W. These faults include map-scale thrusts and strike-slip faults. Field observations confirmed the presence of lower-order faults and folds with orientations consistent with those identified in LiDAR data. However, direct identification of specific fault surfaces derived from LiDAR data in the field was unsuccessful. Despite this, fault-slip data analysis reveals a strong correlation between the interpreted shortening directions of faults derived from LiDAR and those observed in outcrops across the region. Lithostratigraphic units play a crucial role in deformation - competent rock units primarily accommodate brittle faulting, whereas incompetent units are more prone to refolding. While strike-slip faults are widespread, they are predominantly localized within the most competent units, whereas thrust faults occur regardless of the mechanical competence of the rock units.

This integration of LiDAR with field data reduces uncertainties in structural interpretation, providing a more robust framework for analyzing fault networks and their role in fluid migration. These findings highlight the importance of integrating remote sensing techniques with field studies for geological mapping and structural analysis.

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Provenance of siliciclastic detritus from Cretaceous synorogenic basins in the NW Dinarides based on zircon U-Pb ages

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The present-day complex geology of the Dinarides is a consequence of convergent processes between the Adriatic and European plates. This convergence started during the Early to early Middle Jurassic with intra-oceanic subduction, followed by Middle to Late Jurassic ophiolite obduction. Obduction was followed by nappe stacking and synorogenic basin formation on the Adriatic plate. Cretaceous synorogenic basins were filled by clastic detritus composed of various amounts of carbonate and siliciclastic material, providing crucial information about the composition of eroded and exhumed source terrains. Our study in the area of the NW Dinarides focuses on the provenance of siliciclastic detritus based on U-Pb age of detrital zircon populations: Early Cretaceous sandstones of Ivanščica Mt. and Late Cretaceous sandstones of Mt. Medvednica and Žumberak Mts. Results obtained by LA-ICP-MS reveal different patterns among the studied sandstones. All samples are characterized by Variscan, Caledonian and Pan-African detrital zircon populations, but in Early Cretaceous sandstones of Mt. Ivanščica, a Permo-Triassic population is significant. The youngest identified grain has a Middle/Late Jurassic age. Conversely, in Late Cretaceous sandstones of Žumberak Mts. the Permo-Triassic population is represented by a single grain of Middle Permian age, while on Mt. Medvednica it is completely absent. Another difference between contemporaneous Mt. Medvednica and Žumberak Mts. sandstones is an insignificant population of Variscan zircons and a predominance of older populations on Mt. Medvednica. Interestingly, contribution of Late Cretaceous magmatism has not been identified, although it is present in the neighboring areas. These results affirm previously noticed different source rocks for siliciclastic detritus in the Early and Late Cretaceous, as well as local variability during the Late Cretaceous. In context of available regional data they also indicate diverse source rocks across the Dinarides both during the Early and Late Cretaceous.

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Variscan S-type granitoids in the Tisza Mega-unit: petrology, zircon U-Pb dating, and correlations

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Two-mica leucogranites and granodiorites occur in several parts of the Tisza Mega-unit such as the Apuseni Mts (Codru-Moma and Highiş Mts), southern Transdanubia (Mecsek Mts), the Slavonian Mts (Papuk Mt), and basement areas in the eastern Pannonian Basin (Battonya–Pusztaföldvár Basement Ridge and Algyő–Ferencszállás Basement High); however, despite the similar petrographic characteristics, their relationships were so far unclear, due to the limited amount of available geochemical and geochronological data. In this study, the detailed mineralogy and petrography, bulk-rock major and trace element geochemistry, and zircon (with some additional monazite) U–Pb dating were carried out on the samples of the abovementioned areas to better understand their petrogenesis, geodynamics and age constraints, as well as their local and (sub)regional correlations.

Many of these samples were affected by post-magmatic alterations (e.g., Cretaceous hydrothermal effects, Alpine deformation/metamorphism, and/or Miocene tectonics) supported by preliminary sericite K/Ar ages. A significant amount of discordant and Pb-loss zircon U-Pb data and zircon inheritance (i.e., xenocrysts) is also common. Based on the restricted reliable age data, at least three distinct periods of syn-collisional, S-type granitoid magmatism were revealed in the Tisza Mega-unit. The oldest data, obtained for the orthogneisses in the Papuk Mt, yielded an Early Ordovician (~480 – 475 Ma) age. Early Carboniferous ages (~360 – 340 Ma) were constrained by the granitoids of the Apuseni Mts and the Battonya–Pusztaföldvár Basement Ridge, which, supported by their similar geochemistry, suggest local correlations between them. These formations show close similarity in age and chemistry with the analogous orthogneisses and granodiorites in the Western Carpathians. The youngest, middle Permian (~270 Ma) age was calculated for monzogranite pebbles from the Mecsek Mts.

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Alpine garnets under pressure: exploring chemical and mechanical modifications in Dora Maira whiteschists

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The Dora Maira Massif, one of the internal crystalline massifs of the Western European Alps, consists of basement nappes belonging to the Penninic Domain. It is distinguished by the presence of high-pressure (HP) and ultra-high-pressure (UHP) rocks, most notably the coesite-bearing whiteschists. These rocks serve as valuable records of Earth's subduction-exhumation cycle and provide insight into (U)HP mechanical processes. As a result, Dora Maira whiteschists have been a focal point of petrological research for the past four decades. However, while most studies have concentrated on their petrological characteristics, the unique microstructures of these rocks remain relatively underexplored.

This study presents preliminary findings from a microstructural and compositional analysis of the whiteschists, with a particular emphasis on garnet crystals. The foliation within these rocks varies spatially and is defined by the alignment of phengite and garnet crystals. Palisade quartz develops locally at the borders of garnet crystals and between phengite grains, typically oriented at a high angle to the primary schistosity. Additionally, palisade quartz is observed within garnet crystals, either surrounding or entirely replacing pre-existing coesite inclusions. Garnet grains exhibit two main morphologies: elongated parallel to foliation and rounded. They also display two distinct fracture patterns, one set aligned at high angle to the rock's foliation and another forming radial fractures around coesite/palisade quartz inclusions. The latter fractures are attributed to the volume expansion that occurs during the coesite-to-quartz transition.

To investigate these microstructural and compositional features, we employed SEM-EDS, (HR-)EBSD, and microprobe analyses. Garnet compositions range from ~88 % to 98 % pyrope, but notable chemical zoning occurs around inclusions and within crystals, with an increased grossular component. These findings raise questions about the mechanical behavior of garnets under UHP conditions. Specifically, the volumetric expansion associated with the coesite-quartz transition appears to induce mechanical modifications within the host garnet. A key question remains: could these phase-transition-induced fractures also drive chemical redistribution within the garnet? While further research is necessary, our results suggest a significant mechanical influence on garnet behavior in these rocks. Comprehensive microstructural and compositional analysis is essential to unravel the intricate history recorded within pyrope crystals.

Pressure-temperature history of eclogite facies rocks with reaction overstepping during metamorphism

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Mineral reactions during metamorphism are controlled by fluid availability and deformation. In dry rocks, a delay in mineral formation relative to their pressure-temperature stability fields may occur. This phenomenon can be identified through thermodynamic modeling by comparing the calculated mineral abundances and compositional isopleths, obtained using bulk-rock fractionation, with the actual minerals observed and measured in the sample. A chemically heterogeneous lens of dry mafic rocks was selected to quantify the effect of this delay, or reaction overstepping. These rocks reached peak pressure during the eclogite-facies stage, followed by granulite-facies metamorphism. The selected lens is from the Moldanubian Zone in the southern part of the Bohemian Massif near Svetlik.

Studied rocks have varying degrees of recrystallization, the rocks exhibit differences in texture and mineral assemblages depending on their bulk-rock chemistry, primarily the Al, Mg, Fe, and Ti contents. The most common rocks are retrograde eclogites with slightly higher Fe and Ti contents. Their mineral assemblages consist of relict omphacite, garnet, and rutile/ilmenite, along with symplectites composed of plagioclase and amphibole or clinopyroxene. Retrograde eclogites with higher Al and Mg contents contain similar minerals but also include epidote-group minerals as inclusions in garnet. Samples with the highest content of Al also contain Cr-bearing kyanite as inclusions in garnet. In these samples spinel occurs in pseudomorphs after kyanite and epidote-group minerals, forming as a result of garnet decomposition. Granulite facies minerals, including anorthite-rich plagioclase, orthopyroxene, amphibole, and clinopyroxene, are primarily found in the symplectites. During retrogression from granulite-facies conditions, new amphibole grains grow, forming poikiloblasts that overgrow other minerals and their textures.

Pressure-temperature (P–T) conditions and the metamorphic P–T path of the studied rocks were determined using compositional isopleths of garnet and exchange thermobarometry. The stability fields of minerals and compositional isopleths of garnet were calculated using a Gibbs free energy minimization approach with Perple_X software. The prograde P-T path during the eclogite-facies stage was constrained using CZGM software, which runs in MATLAB. The results of these calculations revealed an occurrence of the reaction overstepping of garnet formation to approximately 2 GPa and 530 °C. The stability fields of kyanite, in combination with epidote-group minerals and modeled compositional isopleths of garnet, indicated peak metamorphic conditions in the eclogite-facies stage at 2.5 GPa and 600 °C. During decompression from the eclogite-facies stage, the rock body experienced heating with heterogeneous re-equilibration under granulite-facies conditions. In addition to modeling in Perple_X, two-pyroxene and garnet-pyroxene thermobarometry, based on THERMOCALC software using the “average P-T” option, was applied. The estimated average temperature was 834 °C at a pressure of 1.01 GPa. Diffusion modeling in garnet using CZGM software indicated that the granulite-facies overprint was short-lived, occurring after the partial exhumation of eclogite and lasting approximately 1 million years.

Diachronous pulses of Variscan magmatic activity in the Eastern and Western Erzgebirge (Germany and Czech Republic), their relation to ore formation and exhumation history

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Two magmatic periods have been proposed in the Erzgebirge: a late Variscan (ca. 325 – 315 Ma), and a post-Variscan (ca. 300 Ma). Until now, only few data exist for the second period. We analysed 13 samples from granites and rhyolites that have been suggested to belong to the second magmatic period. Zircons of these rocks were dated with the high-precision U-Pb chemical abrasion-isotope dilution-thermal ionization mass spectrometry. Seven samples belong to the post-Variscan period (305 – 296 Ma), among them are two granites that were not known before. A compilation of all high-precision zircon ages records distinct periods of magmatic activity in the Erzgebirge. Based on this compilation we provide the first evidence that the magmatic evolution in the Erzgebirge was diachronous, since magmatism occurred earlier in the Western Erzgebirge (323 – 313 Ma, 306 – 303 Ma) compared to the Eastern Erzgebirge (315 – 310 Ma, 301 – 296 Ma). In both parts of the Erzgebirge, these two magmatic stages are associated with abundant hydrothermal ore formation. Early Variscan melts are more magnesian compared to later and post-Variscan melts, which have ferroan and anhydrous character and commonly share some characteristics with A-type granites. The dominant protoliths of all Variscan melts were crustal quartzofeldspathic rocks with likely minor contribution of mantle material. Based on the earliest records of volcanic rocks, an earlier onset of uplift and exhumation of the eastern part of the Erzgebirge is assumed, whereas the uplift began later in the western part but reached deeper erosion at the present-day level.

Preliminary elaboration of a 3D crustal model of the Moldanubian and the Bruno-Vistulian domains, southeastern part of the Bohemian Massif

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An upgrade of the crustal structures of the southeastern margin of the Bohemian Massif comprising the Moldanubian and Bruno-Vistulian domains is presented, based on 3D forward magnetic and gravity modelling, constrained by geological data, seismic refraction (SUDETES 2003) and petrophysical data.

The Moldanubian domain consists essentially on Neoproterozoic to Carboniferous metamorphic units (Monotonous Group, Varied Group, Gföhl unit) and high grade rocks outcropping in the form of diapiric-shape extrusions, intruded by voluminous anatectic plutons. It is considered as the Paleozoic orogenic root. The Moldanubian–Bruno-Vistulian continental transition zone consists in highly deformed and inverted metamorphism sequences derived from the Bruno-Vistulian, which constitutes the Moravo–Silesian Zone. The juxtaposed Bruno-Vistulian microcontinent, derived from the northern margin of Gondwana, is characterized by a Neoproterozoic intermediate to mafic crust, intruded by granites and overlain by Devonian shallow marine sediments and Carboniferous flysch. All this is the result of late Devonian subduction of the Saxothuringian continent beneath the Teplá-Barrandian Unit and the Moldanubian domain.

The elaboration of a 3D crustal model of the boundary between the Moldanubian and the Bruno-Vistulian domains was already modelled but at a larger scale and without taking into account the magnetic anomalies. In this study, we perform a more detailed 3D model using IGMAS+ software to investigate the deep nature of the Moldanubian/Brunovistulian contact. The particular aim is to try to confirm or exclude the existence of a theoretical suture zone. The model extent covers an area of ~200 km in NE–SW-direction and ~250 km in NW–SE-direction and integrates gravity and magnetic from European compilations and the Czech Geological Survey.

Ordovician metasyenite from the Bíteš Group – an exceptional indication of the Early Palaeozoic extension inside the Brunovistulian domain

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Ordovician (meta)igneous bodies are relatively common inside Moldanubian and Saxothuringian zones of the Bohemian Massif and are related to the Cambro-Ordovician rifting of the northern Gondwana (Žák et al. 2023 for review). On the other hand, no indication of the early Palaeozoic rifting is known from the easterly Brunovistulian domain except peculiar Silurian dykes from the Brno Massif. Data from a sample of amphibole-biotite metasyenite within the Bíteš Group of the Moravicum are the first indication of Ordovician extension in the Brunovistulian Domain. A syenite like rock at the small outcrop in the left tributary of the Chvojnice River could be distinguished from the host Bíteš orthogneiss by its coarse-grained granitic texture and brick-red colour. The coarse-grained metasyenite with granoblastic texture is inhomogeneously deformed and composed mainly of albite (Ab_{96-98}, An_{1-4}, Or_1) and K-feldspar (Or_{97-98}, Ab_{2-3}). Amphibole classified as hastingsite to potassic-hastingsite is preserved in the isomorphic dark blue-green grains and columns in aggregates with brown biotite. Quartz is polygonally recrystallized in narrow bands between feldspar grains.

Two morphological groups of zircons were distinguished in the metasyenite sample.The first group of zircons are mostly elongated with angular shapes, lengths ranging from 130 µm to 260 µm and aspect ratios between 1:1.5 and 1:3. The second group consists of subhedral to anhedral, elongated with aspect ratio 1:2 or isometric with aspect ratio 1:1 and lengths ranging from 260 µm to 390 µm. Despite their morphological differences, the ages of both groups are similar and yield a concordia age of 479 ± 3 Ma (MSWD = 0.16) (LA-ICP-MS on 48 zircon spots).

The rock is classified as metaluminous/peralkaline syenite (A/CNK = 0.93 – 0.91, A/NK = 1.04 – 1.06). The total REE content is 190 – 244 ppm with a relatively low degree of LREE/HREE fractionation (La_N/Yb_N = 4.1 – 4.4) and pronounced negative Eu anomaly (Eu/Eu^* = 0.3 – 0.5). Rock shows only a low enrichment of LILE over HFSE relative to normal mid-ocean ridge basalts, and it is significantly depleted in Sr, P, and Ti.

The rock appears distinctly alkaline (Whalen 1987) and within-plate/anorogenic in geotectonic diagrams. Crustal contamination is negligible according to whole-rock geochemistry and the absence of inherited zircons. These features are evidence for Lower Ordovician extensional magmatism in Moravicum, synchronous with magmatism in Moldanubian unit, representing an initial stage of the Gondwana passive margin rifting and the opening of the Rheic Ocean.

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Dating prehistoric seismicity in the Alps using trapped charge methods on incohesive fault rocks

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This study deals with dating prehistoric seismic activity in the Alps by combining two trapped charge dating methods on quartz and K-feldspar contained in fault gouge (incohesive fault-related rocks formed by frictional grain comminution at near-surface conditions). Our studies focus on the Periadriatic fault system (PAF) between S Austria, NE Italy and N Slovenia. The PAF can be traced for c. 700 km along-strike the Alps and forms an array of post-collisional, predominantly dextrally transpressive strike-slip faults. Instrumental earthquakes along the PAF are rare; historical earthquake catalogues suggest that it could have hosted several damaging events with moment magnitudes Mw up to c. 7.0. Fault gouge is often found in spatial proximity to pseudotachylites (cohesive fault rocks formed at greater depth), testifying to longevity of seismic activity along the PAF. This and the observed discrepancy in fault activity on the timescale of 101 to 103 years (instrumental vs. historical seismicity), motivated us to expand the timescale to 104 – 106 years using trapped charge dating on fault gouge.

The electron spin resonance (ESR) and optically stimulated luminescence (OSL) dating methods rely on the accumulation of unpaired electrons within 'traps' (i.e., lattice defects) in minerals such as quartz and feldspar that can be released by stimuli such as light or heat. These electrons are produced over time mostly by natural decay of radiogenic nuclides contained in rocks. The trapped charges build up to reach a saturation level, after which they can be released from their traps either during periods of increased temperature due to shear heating, elevated stress and frictional grain comminution. Therefore, they potentially allow direct dating of seismotectonic deformation in fault zones at near-surface conditions, requiring only presence of suitable minerals in the samples, and with the assumption that at least partial resetting of the ESR and OSL signal intensities occurred predominantly by coseismic shear heating.

Fault gouge samples were obtained from outcrops spanning c. 350 km along-strike the PAF system. Since the saturation doses of the ESR signals on quartz are larger than the OSL signals on quartz and feldspar, ESR enables establishing a maximum age of the last resetting event of the system, while OSL allows constraining their minimum age when the signal is in saturation. Dating results from 11 sites yielded ESR ages between c. 1.07 and 0.24 Ma and OSL ages ranging between c. 0.20 and 0.28 Ma. These ages are regarded as maximum and minimum ages at which partial resetting of signal intensities occurred due to earthquakes at each site. In combination, we conclude that major portions of the PAF system must have accommodated seismotectonic deformation in the last one million years.

Pyroxene growth kinetics in basalt and andesite as a function of undercooling

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Crystallization and growth kinetics are fundamental to magma differentiation, melt rheology, and emplacement or eruption style. While the growth kinetics of olivine and plagioclase are well-understood, pyroxene growth is difficult to observe experimentally due to a nucleation barrier which obscures the difference between nucleation time and growth time. While isothermal experiments have showed that pyroxene growth rate (G) changes with time, it is unknown how G changes in response to changes in undercooling relative to liquidus temperatures ($\Delta T = T_{liquidus} - T_{experiment}$). We performed petrological experiments at various ΔT to attempt to measure the growth rate of pyroxene as a function of undercooling.

Experimental glasses were synthesized from high purity silicate, oxide, and carbonate powders using average Mid Ocean Ridge Basalt (MORB1) and the composition of the andesitic meteorite Erg Chech 002 (AND1). Starting mixtures were melted in a 1-atmosphere muffle furnace at 1300 °C in a Pt crucible that had been pre-equilibrated with melts containing Fe to avoid Fe loss by alloying. Glasses were crushed in an agate mortar and remelted twice to ensure homogeneity, after which major element compositions were confirmed using Electron Probe Microanalysis (EPMA). Powdered glasses were loaded onto Pt wire loops using polyvinyl alcohol (PVA) as a binder and subjected to various cooling regimes in a 1-atmosphere muffle furnace. The Pt wire was reused for experiments with the same compositions until work hardening rendered it unusable. EPMA analysis of used Pt wire revealed a ~0.5 µm wide Fe alloy had formed along its outer edge, which by mass balance represents Fe loss negligible to the glass composition.

The theoretical liquidus temperatures of both starting compositions were determined using the MELTS algorithm to be ~1200 °C for MORB1 and ~1165 °C for AND1. Initial experiments were carried out for 2 hours close to these temperatures to observe whether pyroxene would nucleate readily. While rare pyroxenes were observed in AND1 at 1160 °C, none were observed in MORB1 between 1210 and 1160 °C. A subsequent 23-hour experiment at 1160 °C showed that MORB1 crystallized plagioclase without crystallizing pyroxene. For this reason, ~10 wt.% of natural diopside seed crystals were added to subsequent MORB1 mixtures. Time series between 0.5 and 24 hours were conducted at various ΔT, after which the widths of growth rims were measured on the pyroxene seed crystals using EPMA. These will be used to quantify the growth rates of pyroxene grains as a function of undercooling.

Microstructural evolution of pencil gneiss of the Kouřim unit

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L tectonites are rocks with only or almost only linear structure that are found in a variety of geological settings and rock types. Their formation indicates nearly perfect constrictional deformation and is described to originate in an overall simple shear kinematic frame. The rock microstructural evolution during the L tectonite formation has been rarely studied because of their relatively small abundance compared to S and S-L tectonites, as well as the complexity of the issue. L tectonites (pencil gneiss) documented in the Kouřim unit formed during a deformation event characterized as largely coaxial pure shear dominated flattening. All linear structures of the respective deformation phase including L tectonites show transpositional character. In the Kouřim unit (Bohemian Massif), located on the northern periphery of Moldanubicum within the Kutná Hora crystalline complex, four tectonic events were identified demonstrating all episodes of the collisional evolution of the Variscan Orogeny.

The aim of this study is to describe the evolution of microstructure during L tectonites formation and its relationship with anisotropy of magnetic susceptibility. This method is used in structural geology for its ability to easily quantify microstructure in rocks. It combines both the shape preferred orientation and crystallographic preferred orientation of all constituent minerals. Samples were collected from two localities where the linear fabrics formed in hinge zones of horizontal folds of the pure shear dominated flattening deformation phase. The localities differ in fold and grain size of the rock. The samples capture the evolution of the structure from limbs to the hinge zone of the folds. The evolution of the pencil gneiss is well imprinted in magnetic fabrics showing significant trends in magnetic fabric strength and shape following evolution of microstructure.

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The National Geological and Hydrogeological Map of Ethiopia

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The foundation of any geological knowledge lies in the systematic mapping of the geological environment. This process provides essential insights into the geological structure, lithological pattern and hydrogeological parameters. The research outcomes have far-reaching implications for the effective management of water resources, sustainable agriculture, infrastructure development, and the assessment, monitoring, and mitigation of geological hazards.

The national geological and hydrogeological map of Ethiopia at a scale of 1:1,200,000 presents a comprehensive synthesis of geological, lithological, petrological, geochemical, and tectonic parameters. It also offers a fresh perspective on the lithostratigraphic framework of Ethiopia's geological environment, supported by remote sensing data and gravity modeling. The geological map was compiled using existing maps of varying scales, extensive datasets, published literature, and new field verification in key areas. This work, conducted between 2019 and 2024 as part of a Development Aid Project funded by the Czech Republic through the Czech Development Agency, aims to address significant gaps in geological knowledge. The resulting map provides up-to-date, relevant, and comprehensive information, which is particularly valuable for groundwater resource assessments as one of the most critical aspects of Ethiopia's natural resource management due to increasing demand. In addition, the national geological map of Ethiopia records a diverse geological history, from the East African orogeny in the Precambrian, through continental and marine sedimentation in the Mesozoic era, to the formation of the extensive tectonic structure of the East African Rift System and associated volcanic activity from the Eocene to the present. The accompanying hydrogeological map integrates hydrological factors that influence the distribution and capacity of different groundwater aquifers with geological data, creating a robust tool for managing the country's water resources sustainably.

A comprehensive understanding of the geological environment is fundamental to the efficient and sustainable use of natural resources such as land, water, and minerals. We believe this approach is key to fostering sustainable socio-economic growth and ensuring the well-being of future generations, particularly in a country as exceptional and geologically diverse as Ethiopia. Ethiopia is one of the Czech Republic's priority countries in the field of development cooperation, reflecting the long-standing and excellent relations between the two nations. It is, therefore, a great privilege that the Czech Republic has been able to contribute significantly to the understanding of Ethiopia's geological framework through joint development cooperation projects.

Melt-assisted zircon modification leads to challenges in age interpretation, the South Bohemian granulite massifs

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In metamorphic terranes, zircon spot apparent ages (dates) often show ranges over tens to hundreds of million years, even for concordant analysis. Such datasets have been often interpreted as a result of protracted or repeated high-grade metamorphism. However, these interpretations are doubted as it is difficult to explain how could be high temperature maintained in the crust for such a long time, but also why should be recorded such a large age range in one sample. Another suggested interpretation of these age smears is a variable Pb-loss from zircon during metamorphic modification. However, unrevealing the possible processes for element mobility in zircon puzzled the scientists due to the closure temperature of >900 °C for Pb diffusion in zircon, which is rarely achieved by metamorphic rocks. Limited possibilities for modifying zircon at normal crustal conditions led to consider mainly the role of radiation damage causing amorphous (metamict) zircon structure, subsequently allowing higher element mobility below 900 °C, especially if fluid is involved. More recently, fluid-mediated coupled dissolution-precipitation (CDP), and increasingly considered also melt-mediated CDP are processes that can explain Pb mobility and other chemical changes in crystalline zircon under 900 °C. The zircon ^{207}Pb-corrected ^{238}U/^{206}Pb dates from the Prachatice and Blanský Les granulite massifs span from c. 580 to 330 Ma, with few outliers along discordia heading to c. 2000 Ma. In order to interpret such a large spread of dates we relate the dates with zircon textures and with trace-element and rare earth element composition. Some crystals are sector-zoned or show sector-zoned or homogeneous rims resembling overgrowths, compatible with new zircon crystallization from melt. Other zircon textures show embayments of patchy and structureless domains into oscillatory-zoned crystals, and rarely also secondary mineral inclusions, textures typical of CDP. In weightedmean diagrams of concordant analysis (2 %) some samples show a small plateau at c. 580 – 540 Ma, and a small plateau starting at c. 500 – 480 Ma, characterized mostly by oscillatory-zoned domains, but showing a continuous smear of dates to c. 340 Ma, characterised by faded, patchy and homogeneous domains. In other samples a continuous smear of concordant dates starts at c. 480 Ma, 440 Ma, 400 Ma. We propose that oscillatory-zoned domains with dates of c. 2 Ga, 580 – 540 Ma represent xenocrysts, oscillatory-zoned domains of c. 500 – 480 Ma represent magmatic protoliths. The age smears to c. 340 Ma are caused mainly by a variable Pb-loss, and are accompanied by other element mobility, for example by lowering HREE, typical for equilibrium with garnet. Melt is the main medium in zircon modification, in places the textures are indicative of melt-mediated CDP, but in other places recovery of crystallinity in radiation-damaged zircon or growth from melt are also possible explanation.

Structural control on the epithermal Au-Ag-Pb-Zn-Cu deposit at Banská Hodruša (Štiavnica Stratovolcano, Western Carpathians)

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The Banská Hodruša deposit is located in the central zone of the Štiavnica Stratovolcano, which dates to the Miocene epoch. The research suggests that the mineralisation is located at the base of the volcanic sequence, within a discovered low-angle normal fault zone that generally exhibits a flat inclination (0 – 25°) with an average azimuth of 120°. The mineralization is characterised by stockwork and individual veins with varying dips (10 – 90°) within this low-angle normal fault zone. This zone forms at the lithological boundary between the Miocene granodiorite pluton (13.44 ± 0.08 Ma) and the hanging wall units, which consist of sediment fragments (mainly Mesozoic limestones) and the first-stage andesite further up the sequence. The central stockwork (Karolína vein system) exhibits a trishear geometry, with a typical upside-down triangular shape, where the triangle's base lies at the subhorizontal roof of the low-angle normal fault zone. The later Krištof-type veins are primarily represented by NNE–SSW striking tension gashes with moderate dips to the ESE. The Agnesa-type veins, contemporaneous with the Krištof veins, typically dip at shallow angles (less than 30°) towards the ESE. Structurally, these veins form in gentle releasing bends mainly at the upper parts of the low-angle normal fault zone. The precious metal mineralisation was terminated by quartz-diorite porphyry sills 13.31 ± 0.08 Ma old; therefore the age of the mineralisation is estimated roughly at 13.44 – 13.31 Ma based on U–Pb dating. The late post-caldera vein system of Pb-Zn-Cu-Ag-Au veins (12.3 – 11.4 Ma), formed in an extensional tectonic regime, and it is represented by NNE–SSW striking veins with an average dip of 50 – 70° SE. These veins displace the low-angle normal fault-related mineralisation and represent the final phase of hydrothermal activity in the ore district.

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Alpine tectonic evolution of the Tatra Mountains (Western Carpathians) inferred from structural, sedimentary and fission track data

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The Tatra Mountains, located in the northernmost part of the Central Western Carpathians, experienced a complex Alpine tectonic evolution. This study combines structural, sedimentary, geomorphological, and fission track data to examine the tectonic and landscape evolution of the Tatra Mountains from the Cretaceous to the Quaternary period. The mountains and their surrounding areas experienced a complex Alpine tectonic evolution, which can be categorised into several tectonic stages based on structural, sedimentary, geomorphic, and fission track (FT) data.

A first tectonic stage (~110 – 80 Ma) can be dated back to the late Early Cretaceous and is coeval with nappe stacking. At this time, the Tatric crystalline basement was buried below the Eo-Alpine – Fatric and Hronic nappes. The fully annealed zircon samples suggest the metamorphic temperature was over ~300 °C. This main compressional phase of the Alpine orogeny was succeeded by the collapse of the orogen during the Late Cretaceous to Paleogene, as indicated by structural and zircon fission track data from 70 to 60 Ma. This extensional tectonic regime was later replaced by a phase of transpression to transtension during the Late Paleocene to Eocene period (~60 – 40 Ma).

The Late Eocene to Earliest Miocene period is characterised by the formation of a marginal sea within the Peri-Tethyan Basin, represented by the Central Carpathian Paleogene Basin. This basin reflects a fore-arc basin position, developed along the destructive plate margin and situated behind the External Western Carpathian accretionary wedge. During the deposition of the Paleogene sedimentary sequences (~45 – 20 Ma), the crystalline basement of the Tatric Unit experienced thermal conditions between the apatite and zircon partial annealing zone (ca. 200 – 100 °C).

The final cooling of the Tatra massif resulted from asymmetric exhumation, which can be associated with the Subtatric Fault along the southern edge of the massif since 20 Ma. The exhumation of the Tatric crystalline basement from a depth of approximately 5 km occurred during the Middle Miocene to Quaternary, as indicated by apatite fission track data.

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Grain-scale melt percolation in the crustal-scale shear zones in southern Madagascar

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Southern Madagascar is characterized by an anastomosing network of shear zones that crosscut the UHT/HT basement. These 15 – 25 km-wide, N-S oriented ductile shear zones developed between ~580 and 500 Ma, and are coeval with melting and UHT/HT metamorphism. This study focuses on the Ihosy shear zone, where cordierite-sillimanite-garnet gneisses and metagranitoids are exposed, with peak metamorphic conditions estimated at ~750 °C and ~5 kbar. In the field, we observe a gradual transition from orthogneiss and/or tonalitic gneiss to isotropic granite, with intermediate granite types preserving relics of the original gneissic banding. Within this sequence, we have established four rock types: mylonitic gneiss (Type I), migmatitic gneiss (Type II), granitic gneiss (Type III) and granite (Type IV). All types consist of quartz + plagioclase + K-feldspar + biotite ± garnet ± cordierite ± sillimanite, with accessory amounts of magnetite, monazite, zircon and apatite. Type I is characterized by well-defined grain boundaries, large feldspars and small amount of interstitial grains. Type II exhibits large feldspar grains with slightly cuspate and corroded-like shapes. Towards Type IV, these original large grains are getting more corroded, while the amount of the new interstitial grains is increasing. Presence of former melt was documented in all four types as either narrow films along grain boundaries, small grains in triple point junctions or pools of newly crystallized grains, where grain boundaries can be difficult to delineate. In order to quantify textural changes, we digitized thirty thin sections from different rock types and conducted a quantitative analysis using the PolyLX toolbox. The modal proportions of feldspars and quartz evolve towards a more granitic composition from Type I to Type IV. Throughout the sequence, Crystal Size Distribution (CSD) analysis suggest an initial high nucleation rate of K-feldspar, followed by progressive growth towards Type IV. Conversely, plagioclase and quartz exhibit initially growth, which is later overtaken by increased nucleation. Feldspars grain size increases, while quartz grain size remains constant throughout the sequence. The distribution of like-like feldspar contacts evolves towards a random distribution in Type IV, with no apparent preferred orientation of the newly formed grains. However, the shape preferred orientation of all phases is relatively strong. We suggest that the transition between the mylonitic gneiss and the isotropic granite is a result of melt migration in the shear zone and the different rock types reflect different degrees of equilibration between the host rock and the passing melt. We propose that the shear zone is the site of a large melt transfer from the depths. This melt infiltrates the surrounding rocks both as discrete bodies (e.g. vein and dyke networks) and also pervasively at grain-scale, progressively fluxing the host rock and changing its macro- and microscopic appearance.

U-Pb and Hf isotope record in zircon of the Gföhl orthogneiss

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The Gföhl Metamorphic Unit in the Bohemian Massif consists of migmatitic orthogneiss and paragneiss, granulite and eclogite. It is considered to represent a deep crustal unit that records a polyphase tectono-metamorphic evolution that reached (U)HP conditions and culminated in widespread anatexis and exhumation at around 340 Ma. Recent geodynamic models of the Bohemian Massif suggest that a large part of the Gfohl unit may represent relaminated crust of the Saxothuringian lower plate. We aim to test this hypothesis by identifying the pre-Variscan history of the Gföhl unit and comparing against established data from Saxothuringia. For this study we targeted migmatitic orthogneiss of the so-called Gföhl gneiss, which is the largest metaigneous unit in the Eastern Bohemian Massif, for zircon isotopic study. Four samples from the Gföhl gneiss come from the Krems river valley, Austria, and four samples from the Rokytná valley, Czechia. Zircon grains commonly display cores with sharp oscillatory zoning typical of magmatic crystallization. However, the oscillatory zoning is often blurred or faded, and rims are formed by CL-dark domains that in places form embayments into oscillatory and faded domains. The single spot dates show significant spread with range from 1915.7 ± 35.1 to 335.6 ± 7.6 Ma. Nonetheless, concordant spots from sharp oscillatory-zoned domains show a dominant peak at c. 480 Ma, and a smaller peak at c. 550 Ma. Dates from faded and patchy domains show tails down to c. 335 Ma and dates from homogeneous BSE-dark rims are c. 340 Ma. A few spots are arranged along a discordia line heading to c. 2 Ga, witnessing recycling of Paleoproterozoic crust. We interpret the ages at c. 550 Ma as inherited from the source of the magma, c. 480 Ma as the protolith age and c. 340 Ma as the age of zircon modification during anatexis. The tails of single dates which extend to c. 340 Ma are interpreted as a result of incomplete zircon modification during melt-mediated coupled dissolution-precipitation, and therefore geologically meaningless. Hf in zircon isotopic data from both the c. 550 Ma and c. 480 Ma zircon cores give generally negative, but slightly dispersed, $\varepsilon Hf_{(t)}$ values with median values of −5.6 and −4.2, respectively. The c. 340 Ma rims have concentrated negative $\varepsilon Hf_{(t)}$ values (−2.6 to −8.0). The Cambro-Ordovician protolith age of the Gföhl gneiss, their late Neoproterozoic inheritance, and evolved isotopic composition all bear a strong resemblance to published data from orthogneiss from Saxothuringia and therefore are permissive of a potential link between the Gföhl gneiss and relaminated lower plate crust.

Petrological and geochemical assessment of the formation of mafic–intermediate pyroxene granulites at the contact between Ky-bearing felsic granulites and garnet clinopyroxenites (Dunkelsteiner Wald, Gföhl Unit in Lower Austria)

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Kyanite-bearing felsic granulites (Ky–Grt–Kfs–Pl–Qz ± Bt) in the Moldanubian Gföhl Unit represent strongly metamorphosed Saxothuringian metaigneous lithologies subducted beneath the Moldanubian orogenic root domain. They host cm- to km-scale garnet clinopyroxenite (Grt–Cpx ± Opx ± Pl ± Amp ± Spl) and mantle peridotite bodies incorporated during subduction. Intermediate (Grt–Kfs–Pl–Qz–Opx ± Bt) to mafic granulites (Grt–Cpx ± Opx ± Pl ± Amp ± Spl) occur locally at the contact between garnet clinopyroxenites and host granulites. This research assessed whether the transitional granulites of the Dunkelsteiner Wald massif could have formed by interaction between Ky-granulites and adjacent clinopyroxenite bodies.

Petrogenesis of mafic granulites required the transfer of Ca (+ Mg, Al) from the garnet clinopyroxenites to the Ky-bearing felsic granulites and the migration of K and Na in the opposite direction, which caused the breakdown of Cpx and the formation of the symplectite texture (Pl – Cpx ± Opx ± Amp ± Spl). For the formation of intermediate granulites, the addition of Ca (+ Mg) to the Ky-bearing felsic granulites from clinopyroxenites is required, leading to the breakdown of the Al_2SiO_5 phase (probably Ky) and the stabilization of Opx. Based on the Sr–Nd isotopic data, the intermediate–mafic granulites reflect binary mixing between the symplectite-bearing garnet clinopyroxenite ($^{87}Sr/^{86}Sr_{340}$ ~ 0.7030, εNd_{340} ~ +6.8) and felsic Ky-granulite ($^{87}Sr/^{86}Sr_{340}$ ~ 0.7183, εNd_{340} ~ −7.1). Fitting a mixing hyperbola in the $^{87}Sr/^{86}Sr_{340}$–εNd_{340} space implies that intermediate granulites could contain c. 15 – 30 wt.% of the mantle component, which is in good agreement with the mass balance of major elements. In contrast, Sr–Nd isotopic signature of the mafic granulites requires 10 – 30 wt.% of the crust.

The component exchange probably occurred by diffusion, augmented by the presence of fluid/melt. It could have been accompanied by hybridization in solid state when the rocks came into contact during subduction of the Saxothuringian plate beneath the Moldanubian orogenic root domain.

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Formation of Miocene ultrapotassic rocks in the Lhasa Terrane, Tibetan Plateau: A relamination mechanism

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The petrogenesis of ultrapotassic rocks in the Alpine-Himalayan realm has been extensively discussed but remains obscure. The prevailing model involves partial melting of enriched lithospheric mantle metasomatized by subducted crustal components, while the mechanisms by which the crustal components were delivered to the magma source region remain poorly understood. In this contribution, petrogenesis of Miocene ultrapotassic rocks of the Lhasa Terrane, Tibetan Plateau, is investigated via an integrative evaluation of their geochemical characteristics and geological context, in combination with thermodynamic modelling. It is shown that the ultrapotassic rocks are compositionally distinct from the contemporaneous K-rich shoshonites and adakites, and are exclusively restricted to the western Lhasa Terrane, where the Indian crust is underthrusting. Thermodynamic modelling demonstrates that partial melting of a mixture of Indian graywacke and Yarlung Zangbo ophiolite at 20 – 25 kbar (approximately 60 – 80 km in depth) and at 1200 – 1330 °C can generate magmas that compositionally resemble the ultrapotassic rocks of the Lhasa Terrane. Such high temperature conditions are supported by P–T conditions inferred from crustal xenoliths in ultrapotassic rocks. We propose that partial melting of the relaminated subducted Indian crust and oceanic components at a sublithospheric level is a viable mechanism for generating ultrapotassic magmas in the Lhasa Terrane. We speculate, that this mechanism may also contribute to the formation of ultrapotassic magmatism in continental collisional belts.

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