18TH MEETING OF THE CENTRAL EUROPEAN TECTONIC STUDIES GROUPS
25TH MEETING OF THE CZECH TECTONIC STUDIES GROUP

Book of Abstracts

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Terchová, Slovakia
CETEG

18th Meeting of the Central European Tectonic Studies Groups (CETeG)
25th Meeting of the Czech Tectonic Studies Group (ČTS)

BOOK OF ABSTRACTS

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Obsah

Preface

The Central European Tectonic Group (CETeG) is an open scientific association bringing together the geoscientists with the interest in geodynamic processes of the Earth crust in a broad measure. The first CETeG conference was launched in April 2003 as an extension of the 8th meeting of the Czech Tectonic Studies Group held in Hrubá Skála (Czech Republic) with the aim to vitalize the international cooperation and exchange of scientific information in all tectonics-related aspects of geology in Central Europe and worldwide. Former Czech-Polish-Slovak contributions presented in their native languages were changed for English to allow a broader international participation. The international character of annual CETeG meetings intensified during all the following events over the next nearly twenty years, organized each year in a different member country (Czech Republic, Slovakia, Poland and Hungary).

An important mission of the CETeG conferences is to introduce young scientists and students on the international scientific forum. Each year, there is a competition for the best student oral presentation and the best student poster. Moreover, every other year nominations for the Radek Melka Prize are announced for the best student or young scientist paper published in an international geological journal. All winners are awarded by the financial support. However, this well run-in schedule was unexpectedly interrupted in 2020 by the Covid-19 pandemic, which forced us to postpone the CETeG 2020 meeting three times – from April 2020 to October 2020, then to April 2021, and finally to September 2021. Hopefully, this deplorable situation will not repeat in the future again.Financial prizes for students went to Czech Republic and Poland this year. Jan Kulhánek from Charles University, Prague was awarded for the best oral presentation and Riccardo Callegari from AGH University of Science and Technology, Krakow was awarded for the best poster presentation.

The venue of the 18th CETeG meeting in Terchová was situated at the contact zone of the Pieniny Klippen Belt (PKB) with the Central Carpathian Malá Fatra Mts. This was the fourth meeting in row, which has been organized in surroundings of the PKB and where the field trips were at least partly focused on the structure and evolution of this peculiar Western Carpathian tectonic zone. Previous events were held in the western PKB branch (6th CETeG 2008 in Upohlav, Middle Váh River Valley of western Slovakia), in the eastern branch (10th CETeG 2012 at Medvedia Hora in easternmost Slovakia), and then 16th meeting 2018 in Rytro, southern Poland, with an excursion to the Pieniny Mts). The recent session and the post-conference excursion were located in the NW part of the PKB arc, thus they nearly complete its regional extent. Nevertheless, the PKB structure is so complex and regionally variable that we do expect it will be a focus of some forthcoming CETeG meetings again.

The need for understanding brittle deformation of bedrock in a safe nuclear waste disposal project

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The most important requirements for the nuclear waste disposal project are related to the long-term safety of the repository. In deep geological disposal concepts used in crystalline bedrock environment, the main role of the bedrock is to provide a stable environment for the engineered barrier system to retain their isolation properties. Thus, it is generally recognized that the requirements for the host rock should cover the issues of mechanical stability and favorable groundwater conditions.

The mechanical stability, local seismic risks, evolution of groundwater chemistry, flow rates and transport properties are all strongly controlled by the features of brittle deformation, faults and fractures. This sets needs for mapping, interpreting and modeling the structural elements of the bedrock in a repository site. The data acquisition is covering the fabric of intact rock in the site, general characteristics of brittle deformation features, fracture data collection and processing, characterization of brittle deformation zones and identification of fracture and fault systems. The data are collected from the bedrock surface, drillings, underground facilities and by lineament interpretations and other interpretations based on geophysical data.

The geological data are used for conceptual understanding and building deterministic and stochastic models. In a nuclear waste disposal project, typical downstream users of geological data and models are modelers of other disciplines, such as hydrogeology and rock mechanics. Also safety assessment team and those who are responsible of design, construction, licensing and operation of the repository are using results of geological investigations. Therefore, geologists need to be able to answer questions about the host rock during the operation but also about the future evolution: what are properties of the connected fracture network, properties of fracture surfaces, stability during construction, geometry and relationship of the fracture systems, paleostress, paleogeochemistry, major faults and potential movements in future, and which are the suitable rock volumes for disposal facilities.

One example of extensive characterization programs of brittle deformation is Posiva's project in the Olkiluoto site, Finland. Geological investigations started in the early 1980s, and after a multi-stage process, Olkiluoto was selected for the final disposal site of spent fuel from the Olkiluoto and Loviisa nuclear reactors. During this long process, geological investigations have been in a major role in the disposal project and its licensing and acceptance, but mutually the disposal project has been beneficial for developing investigation methods and better knowledge of bedrock in general.

The structural evolution of Paskhand salt diapir in the Cenozoic formations and deformation of the Zagros Fold and Thrust Belt, Iran

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The Zagros Fold and Thrust Belt (ZFTB) is 1800 km long and trends as NW-SE part of the orogeny interpolating the Alpine-Himalayan Orogenic Belt. The tectonic history of these parallel belts generally consists of three steps: stable platform in Paleozoic, extension and rifting in the ocean in Jurassic-Early Cretaceous; ophiolite emplacement in Late Cretaceous and finally, collision and crustal shortening in the Cenozoic. The Hormuz salt basin is limited westwards against the normal paleo-faults bounding of the Qatar Arch and stable Arabian Plate but extends northwards in the southeastern Fars province. More than 200 salt diapirs have been identified in the Persian Gulf and the Zagros Mountains. Many of these diapirs were emergent before the Cenozoic collision and development of the ZFTB. Reactivation of salt diapirs during the Cenozoic collision is recorded by the deformation and sedimentary deposits in the surrounds of the salt diapirs. To understand the diapiric activity and interaction of the diapir deformation together with the host rocks during the development of ZFTB, we focussed on the Paskhand salt diapir located 35 km south of Lar city in the Fars province. This nearly elliptical diapir (length:2.5 km, width: 1.5 km) penetrates the crest of the Paskhand Anticline and is embedded by the Oligocene and Miocene sedimentary rocks (Asmari, Gachsaran, and Mishan formations). The Paskhand Anticline is an asymmetric detachment fold developed by the Phanerozoic sequence above the viscous Hormuz evaporite series. Hormuz evaporite series includes numerous carbonate interlayers, siliciclastic and volcanic rocks. Paskhand diapir does not contain rock salt but consists of gypsum, anhydrite and black dolomite layers up to ~10 m thick. The reactivation of the diapir related to the development of ZFTB is reflected in the deformation and sedimentary record of the host rocks. We identified five stages of this reactivation. In the late Oligocene Asmari Formation, exposed only on the western edge of the diapir, the limestone beds show north-south trending folds and westward verging thrusts intercalated by white and pink calcite bearing hydrothermal veins. Miocene Gachsaran Formation shows alternating beds of white sandstones and gypsum-rich layers overlain by carbonates interspersed by alluvial fans formed by conglomerates of Hormuz clastics derived from the diapir. This sequence shows an imbricated thrust system behind the southern edge of the diapir. The Guri Member above the Gachsaran Formation reveals upturned strata reflecting the diapiric draping of the unlithified sedimentary layers – the halokinetic sequence. This is overlain by an onlapping sequence of subhorizontal younger layers of the same Guri Member.

The entire sequence can be interpreted as follows: 1) The collision pressurized the diapir that pushed the surrounding Asmari carbonate layers sideways, along the axis of the large anticline. This deformation was likely stimulated by high fluid pressures in the hydrothermal vein system, 2) initial upheaval of the diapir with respect to the regional datum is reflected by alternating gypsum and sandstone layers (lower Gachsaran), 3) information of alluvial fans shedding the dolomite blocks from the diapir into the reefal carbonates, and 4) development of halokinetic sequence of the upturned beds (Guri Member). Finally, the onlap of the same Guri Member layers above the halokinetic sequence suggests that the reactivation stage terminated during the deposition of this Guri Member.

Major faults in the Sudety Mountains (SW Poland) explored with magnetotelluric method

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The Sudety Mountains define a large, composite fault block on the NE margin of the Bohemian Massif, uplifted in Late Miocene times with respect to the Fore-Sudetic block in the northeast and to the Late Paleozoic through Mesozoic basins (notably the Bohemian Cretaceous basin) in the southwest. The Sudetic block itself contains a number of smaller, but still tens of kilometers long and/or wide blocks, mutually displaced on steep-to-vertical fault zones. These fault zones are, as a rule, of originally strike-slip, Carboniferous origin. They became reactivated in end-Cretaceous and, subsequently, in Late Miocene to Pleistocene times as dip-slip events. From these fault zones, the most well-known is the ~150 km long Sudetic Boundary (or Marginal) Fault, delineating a regional-scale spectacular fault scarp. The other major fault zones, well expressed in the topography, are among others, those that define (1) the upper Nysa Kłodzka Graben, (2) the northern and eastern rims of the Karkonosze mountain range and the Jelenia Góra Basin and (3) the Góry Sowie Mts block. Such steep, subvertical fault zones of complex geometry, reach to a depth of several kilometers and can be successfully traced and imaged with continuous magnetotelluric (MT) sounding method down to 4 - 5 km into the bedrock, the latter being of mostly crystalline character. The crystalline lithologies of bedrock in the Sudetic region, imply that deep, underground thermal waters, prospecting for which is the ultimate goal of the project here reported, circulate in the bedrock mostly or exclusively along tectonic fracture zones, such as composite faults and/or “fracture corridors”, i.e. bands of intense jointing. Our MT sounding was carried out along, altogether, 16 profile lines from ~2 to 7.5 km long, crossing the Sudetic major fault zones at different locations. Altogether >40 km of MT profiles were accomplished. Our MT profiles show the gross structure of the fault zones down to 4 - 5 km presented in terms of electro-resistivity variation images, where zones of lowered resistivity of the rock medium likely correspond to deep-reaching (saline and possibly thermal) water-filled conduits along damage zones of the major fault discontinuities. The imaged fault damage zones locally achieve as much as 400-500 m in width and usually they occur in pairs or triplets, sometimes with anastomosing interrelationships. Together, they constitute major, regional-scale brittle fault zones that can be seen on MT profiles. All of the investigated Sudetic fault zones are characterized by planar (not listric) geometry of the component structural discontinuities – at least at the depth levels (4-5 km) covered by reliable MT imaging.

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Heavy mineral analysis of the Senonian exotics-bearing deposits in the Western Carpathians and its paleogeographic and paleotectonic interpretation

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Samples from 30 localities of the Senonian (Coniacian to Maastrichtian) exotics-bearing deposits were analyzed for heavy minerals. They are mostly from the Pieniny Klippen Belt (Klape and Kysuca units), but there are also 3 samples from the Považský Inovec Mts. (1 from the Belice Unit and 2 from the Tatric Unit at the newly discovered Striebornica locality).

In comparison with similar sandstones from the Albian deposits, the Senonian ones are more variable in composition, filling the whole range from quartz arenites, through sublitharenites to litharenites. The Albian deposits have narrower range from sublitharenites to the upper part of litharenites only.

Percentual ratios of the main heavy minerals are similar to those from the Albian deposits, i.e. the samples are dominated by chrome-spinels, zircon, tourmaline, apatite and rutile. On the other hand, unlike in the Albian deposits, garnet is common in the Senonian samples. Titanite, kyanite, monazite, amphibole, blue amphibole, pyroxenes, epidote, staurolite and sillimanite are very rare (much rarer than in the Albian deposits, rarely exceeding 1 %). The spinels were predominantly derived from harzburgites (supra-subduction peridotites). Most of the tourmalines were derived from metasediments, Fe^{3+}-rich quartz-tourmaline rocks, calc-silicate rocks and metapelites and granitoids. Some had a complex zonation with two phases of tourmaline (schorl-dravite and bosiite), or tourmaline intergrown with quartz. These were likely derived from ophiolitic sources. Garnets are mostly almandinic, indicating their derivation from the rocks metamorphosed up to the amphibolite facies or magmatic rocks. However, there are also common pyrope-almandinic garnets indicating their source from granulitic and eclogitic metamorphic facies.

The results indicate dominance of ophiolites (Cr-spinels, blue amphiboles, and eventually complex-zoned tourmaline) and older sediments (zircon, rutile and the rest of the tourmaline). Zircons are strongly rounded; number of euhedral or subhedral grins is low. The regression analysis shows high correlation between the zircon and rutile, which also indicates their source from older sediments.

Besides some similarity with the older, Albian sediments, the data are also consistent with the data from the adjacent areas, e.g. Eastern Alps, Dinarides and Transdanubian Central Range, which show increase of garnet contents and higher petrographic variability of the arenites.

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Tectonic implication of the Fatira shear zone at Wadi Barud area, Eastern Desert, Egypt

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The Wadi Barud area is located along the Qena-Safaga line, at the extreme southern flanks of the northern Eastern Desert of Egypt, as a part of the "juvenile crust" referred to as the Arabian Nubian Shield that was cratonized during the Pan-African Orogeny (900-550 Ma). This area has evolved within an island arc – back-arc setting due to the oblique convergence followed by the accretion of the oceanic crust northward. The Barud gneissic domal structure strikes roughly in the ENE-WSW direction as opposed to the NW-SE main trend of the well-known metamorphic domes in the Eastern Desert. Field observations and relationships show that the Barud gneisses are described as the highly deformed first magmatic generation, characterized by discrete gneissic bands with xenolithic fragments derived from the island arc metavolcanics. These gneisses possess deformed intrusive contacts with the syn-tectonic calc-alkaline phases as the second magmatic generation, which are strongly obliterated with the late-orogenic alkali-feldspar granitic off-shoots. The low-grade metavolcanics and volcanoclastics are preserved mostly in the structural lows, juxtaposing to the Barud gneisses along NW and ENE striking fault contacts at Gabel Hadrabia and Gabel Fatira, respectively. These low-grade rocks lithologically include meta-andesites in addition to volcanoclastics composed mainly of metatuffs which are intercalated with BIF, especially at Gebel Hadrabia. The field criteria and petrographic investigation of these metatuffs show a gradual change in grain size from laminated metatuffs to lithic metatuffs with a transition to agglomerates that reflects their back-arc setting as we move westward across the Wadi Fatira. The deficiency of structural measurements (e.g foliation and lineation), particularly to the core, where the well-developed gneissic foliation is strongly present and parallel to the mylonitic zone of Fatira Shear Zone, emphasizes the magmatic origin of the Barud gneisses.

The structural relationships and features, like parasitic folds, boudinage structures, plugs and offshoots of granitic composition, indicate the rapid change of the Fatira Shear Zone from semi-ductile to brittle phase during the emplacement of the Barud tonalite-granodiorite batholith. The E-W thrust contacts, which are evidenced by the nearly vertical well-oriented thin amphibolitic bands at the northern and southern porphyries of Barud gneisses, demonstrate an early deformational event. These amphibolites reveal a distribution of the discrete kink band structures, in addition to the monoclinic sigmoidal S-C fabric and rotated fragments within the gneissic bands, emphasizing the transpressive dextral sense of shearing along Fatira Shear Zone with absence of the NW Najd Fault System, in the area of study.

Furthermore, the geochemical analysis of thirty-four powder samples was implemented for both of the Barud gneisses and granitoids, and the low-grade metavolcanics, showing enrichment in LREE and strongly depleted in HREE. The former is considered as I-type subduction related calc-alkaline granitoids intruded into island arc volcanics. The mature continental post-tectonic Dokhan volcanics form a conspicuous mountain strip, oriented in the NE direction, that indicates a late-stage orogenic crustal extension and are represented mainly by Gabel Nuqara and Gabel Fatira at the eastern and western flanks of the Barud area. Petrographically, the Dokhan volcanics are bimodal rocks comprising of both rhyolite and andesite porphyries. The molasse-type sedimentary rocks at Wadi Maqal El-Rashayied are poorly sorted coarse-grained rocks composed of angular rock fragments derived from the exposed rock units. The whole pile is dissected by E-W, NNW-SSE and N-S trending dike swarms.

Syn-tectonic granitic magmatism with possible linkage to Variscan slab break off detected in the Western Carpathians (Malá Fatra Mts.)

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Malá Fatra granite massif within West-Carpathian Alpine architecture forms two magmatic bodies identified formerly from mapping work and petrographic research. There was distinguished “hybrid to oligoclase-biotite granitoids” and relatively younger “Magura granite” as product of Variscan thermal activity. According to recent view, the hybrid and oligoclase-biotite granitoid shows an I-type arc characteristics and Magura granites can be affiliated to S-type collisional granitic suite. The existence of the two individual granite bodies in the Malá Fatra pluton and new LA ICP MS geochronological data became a challenge to re-evaluate granite geodynamic interpretation.

Malá Fatra Variscan basement consists of peraluminous tonalite/granodiorite massif with magnesian-calc-alkaline Cordilleran characteristics and high grade metamorphic complex of metapelites, metaultramafites, and metabasites with relicts of eclogites in garnet amphibolites. The large tonalite/granodiorite massif originated from mixing of hot magmas evidenced by composite andesine plagioclase with relic anorthite-rich cores up to An_{45}, composite Na-rich alkali feldspars with Na_2O more than 2 wt. % in cores, presence of antiperthite plagioclase, zonal apatite, and quartz ocelli. Elevated content of mantle-related elements like V, Ni, Cr and Ba, Sr/Y ratio of 44, steep normalised REE pattern with $(Ce/Yb)_N \sim 18$ and low Sr_i resulted from lower crustal sources with minimum 50 % volume of melted quartz amphibolite of lithospheric mantle. The mantle source in granodiorites reflected also unusual abyndance of magmatic Fe-Ti oxides recording cooling temperatures of 735-756 °C. The diatexite in the metamorphic high grade complex shows the in the area oldest age 362 Ma, which is interpreted as a product of partial melting during Variscan subduction. Ediacaran, Meso and Paleo-Proterozoic relic zircons in the diatexites and in the intrusive tonalite/granodiorites indicate a common recycled crustal source. Exhumation of high-grade metamorphic complex with relics of eclogites accompanied by tonalite intrusion had triggered slab break-off. Following large scale transpressional calc-alkaline Visean granite magmatism in age of 350-341 Ma resulted from melting of lower crust induced by heat flow from rising asthenosphere. In this sense the main Malá Fatra granite massif is syn-tectonic and post-collisional. According to U-Th-Pb monazite datings the Visean tonalite/granodiorite magmatism caused thermal overprinting of older crystalline rocks which is evident from U-Th-Pb monazite datings and newly formed zircons on rims.

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Tectonic structures and paleostress fields in Mesozoic and Paleogene rocks in northwestern Slovakia (Liptov Basin and Veľká Fatra Mts., Central Western Carpathians)

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In our study, we mainly investigate brittle tectonic mesoscale structures and analyse paleostress fields and data orientation in two areas situated in northwestern Slovakia (Central Western Carpathians). Both localities were inspected due to being recently uncovered by commercial engineering-geological surveys.

The first study area is situated on the northern slopes of the Veľká Fatra Mts. Carbonate complexes are well exposed in this area. They consist of Triassic formations of the Hronic Unit (mainly Gader and Wetterstein limestones) and the basal formations of the Subtatric Group (especially conglomerates and sandstones of the Borové Formation). The area has complicated fold and thrust structure. The north-verging folds with E-W oriented fold axis and E-W to ENE-WSW oriented reverse faults were formed during the oldest (pre-Eocene) event. The compressional stress axis was oriented approximately N-S. This event was found only in the Middle Triassic Gader limestones. It is probably connected with the movement of the Choč nappe toward N-NW. The next tectonic event (post-Eocene) already affected all types of rocks - Triassic formations and Borové Formation, as well. This event is characterized by W-E to NW-SE oriented compression. The third tectonic event was in a transtensive stress regime with NE-SW-oriented compressive stress axis at which time mostly conjugate strike-slip faults were created. The last tectonic event (Pliocene?) is characterized by NE-SW oriented normal faults (extensional tectonic stress regime).

The second locality consists of two active quarries situated in the cadastre Ružomberok, on the southwest edge of the Liptov Basin. Structural mapping was focused only on the wider surroundings of the planned expressway, where Upper Triassic dolomites (Hronic unit, bedding is generally dipping to NE), overlying Eocene sedimentary rocks of the Borové Formation (Subtatric Group, dipping to the NNE - NE) and Quaternary deluvial sediments outcropped. The oldest (pre-Eocene) identified tectonic structures are roughly NW-SE oriented reverse faults. They were found only in the Upper Triassic rocks, in the Eocene rocks they were absent. The faults are parallel to the Upper Triassic dolomites bedding directions and their origin was probably connected to the nappe-stacking of the Choč nappe. The next recognised structures (post-Eocene) affected both Triassic and Eocene rocks and are a part of one fault zone which crosses the entire studied area. The fault zone is approximately NE-SW oriented and in meso-scale consists of conjugate strike-slip and normal faults (transtensive stress regime with NW-SE to W-E oriented horizontal $\sigma3$ axis). The last post-Eocene and pre-Quaternary structures are usually conjugate NW-SE oriented normal faults which partly co-existed with previous structures. The youngest (Pliocene?) N-S to NNW-SSE (mainly deepening to the west) and E-W to ENE-WSW-oriented normal faults (mainly deepening to the north in the near surface zone) disintegrate pre-Quaternary surface - but overlying Quaternary (Würm - Holocene) deluvial sediments are not damaged. The fault directions are parallel to the nearby valleys (Revúca River valley in the west and Váh River valley in the north).

It was possible to separate three main tectonic events common for both localities. The first one is the Choč nappe, with a general northward motion during the Late Cretaceous. The next event is characterised by generally NW-SE-directed extension during the transtensive stress regime, which was probably influenced by the Central Slovak Fault System activity (transtensional zone during Middle to Upper Miocene). The last common tectonic feature is a switch from transtensive to extensive stress regime.

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Mid-crustal thrusting in the Variscan basement of the Western Tatras: project outline and perspectives

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The crystalline basement of the Tatra Mountains is composed of pre-Mezozoic crystalline rocks belonging to the Tatric Unit, overlain by Mezozoic and Cenozoic sedimentary cover and nappes of the Fatric Unit. Metamorphic rocks are the most abundant in the western exposures of the basement (the Western Tatra Mts.) and display an inverted metamorphic sequence with high-grade rocks in the hanging wall (the upper unit) and lower-grade rocks in the footwall (the lower unit). Juxtaposition of the metamorphic rocks is related to Variscan thrusting with a top to the S–SE sense of shear under ductile conditions. In contrast, Alpine deformation was brittle with NW-ward polarity. The lower basement unit, up to 1000-m thick, is exposed in a tectonic window and comprises metapelitic mica schists, whereas the upper unit consists of para- and orthogneisses, migmatites and amphibolites with relic eclogites.

Here, we report a preliminary structural dataset from a thrust fault that represents a major tectonic discontinuity in the crystalline basement of the Tatra Mts., separating the upper and lower units. This contribution is related to the exploratory project aiming to constrain the timing, conditions and rates of the mid-crustal assembly of the Western Tatra Mts. (Western Carpathians), exposing the Variscan crystalline basement that was reactivated during the Alpine orogeny. The study area offers a unique opportunity for insight into the 3D structural geometries, due to the unique interaction of geological structures with the topography of the mountains, a situation which is unavailable in other parts of the Variscan Belt. The microstructural record will be unravelled by coupling the methods of electron backscatter diffraction (EBSD) with micro-Computed Tomography (μ-CT), whereas the timing of deformation will be tackled with *in-situ* ^{40}Ar/^{39}Ar geochronology of white mica combined with *in-situ* monazite/allanite U-Pb dating.

The preliminary dataset allows outlining of the project perspectives, including (1) locally: insight into the tectonometamorphic evolution of the easternmost flank of the Variscan basement in Europe; and (2) globally: investigating mechanisms of mid-crustal exhumation and the role of older (Variscan) structures during younger (Alpine) structural reactivation.

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The structure and tectonics of the Čeřínek granite revealed by geophysical and geological methods

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Understanding the structure and tectonics of localities selected for the safety assessment for a deep geological repository for radioactive waste is a key factor in the selection process. In order to prepare relevant data for the selection process, nine localities within Bohemian Massif were studied by geophysical and geological methods, Hrádek locality among them.

The Hrádek locality is set within eastern part of Moldanubian Unit, southwest from the town of Jihlava. The Čeřínek granite stock belongs to the group of the late Variscan intrusions of Moldanubian batholith. The vertical stock probably represents roots of a deeply eroded subsidence structure with the Čeřínek porphyritic coarse-grained two-mica granite in the centre. The Čeřínek granite is surrounded by medium-grained muscovite-biotite Eisgarn granite and metamorphic rocks of Monotonous Group of the Moldanubian Unit.

To describe the structural situation of the locality, geophysical profiling and areal gravimetry was conducted together with geological documentation and mapping along the profiles. Among geophysical works following methods were used: electromagnetic methods (including electromagnetics and time domain electromagnetics), resistivity method, electric resistivity tomography, ground gravimetry, refraction and reflection seismic method and tomography and gamma-ray spectrometry.

From geological field works the regional geological maps were updated, detailed geological maps along the profiles were constructed at the scale of 1: 10 000. The main aim was the detection of fault and fracture networks and lithological boundaries and its type. The textural types of granites were documented with petrology, geochemistry and geochronology.

The outcrop situation is classical with respect to the location in Central Europe with high surface coverage. Thus, there is a lack of direct evidence related to the contact of granitic bodies and surrounding metamorphic rocks. The geophysical data gave (in)direct evidence of the geological structure and tectonic configuration of the locality strengthening the surface geological observations.

The geological and geophysical data have been combined into a newly build 3D geological model of the locality, to the depth of 1.5 km. The multi-disciplinary approach allowed us for more accurate setting of lithological boundaries, their geometry and character. As well, the fault structures were more accurately described with its depth reach.

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Study of nanogranites included in garnets from the Valpelline Series (Australpine Domain, Western Alps)

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Melt inclusions (MI) are small droplets of silicate melt (appearing now from glassy to fully crystallized, i.e., *nanogranite*) entrapped within host minerals during their growth. MI have been extensively used in igneous petrology, igneous geochemistry and volcanology to obtain chemical and physical information on magmatic systems and processes. In the last ten years, melt inclusions have become an important tool even in metamorphic petrology for the study of partially-melted high grade terranes (migmatites and granulites). In this case melt inclusions are trapped during incongruent melting reactions by the growing peritectic host. The studies of nanogranites may provide important advantages to the characterization of partially melted terrains, because they preserve the primary anatectic melts produced in the early stages of crustal melting. Conversely, the composition of leucosomes and S-type granites is not representative of that of primary melts because of differentiation processes such as fractional crystallization, cumulus phenomena and entrainment of peritectic minerals. This work focuses on the investigation of high-grade metapelitic rocks (*kinzigites*) from the Valpelline Series of the Dent Blanche nappe (Valle d'Aosta, Italy) and on the characterization of the melt inclusions hosted in peritectic garnet. These rocks belong to the Australpine domain of the western Alps and represent portions of the southern continental margin of the alpine Tethys. The partial melting in these rocks occurred at about 750-850 °C and 6-8 kbar during the Permian (300-250 Ma).

One hundred and one samples have been collected from the Valpelline Series and seventy-seven thin sections have been prepared from them. Subsequently a preliminary work with the optical microscope has been done in order to identify the most promising samples for the study of MI. The mineral assemblage of samples is: quartz + biotite + garnet + plagioclase ± K-feldspar ± sillimanite; rutile and graphite are present as accessory phases. A detailed microstructural characterization has been performed on selected samples using electron scanning microscope (SEM-EDS). The inclusions are small in size (< 20 µm) and are of primary origin as testified by their distribution in the cores of peritectic garnet. They are formed by a polycrystalline assemblage of quartz + plagioclase + K-feldspar + biotite; no glassy inclusions have been found in any samples.

An important goal of this work was the re-homogenization of nanogranites in order to recover the bulk composition of the trapped melt. This has been done via remelting experiments under confining pressure at the Experimental Petrology Laboratory of the Department of Earth Sciences, University of Milan, using an end-loaded piston cylinder apparatus.

Chips of garnet were used for these experiments. They had a thickness of 200-300 µm and were obtained from the thick sections observed with transmitted light microscope. Two different preparations were adopted. In both experiments three garnet portions having size about 2 mm were introduced into a gold capsule (99% Au) with an external diameter of 3 mm. In the first experiment, chips were isolated from each other with silica powder while in the second one graphite was used. The capsules were welded and inserted into a sample holder made of MgO salt, enclosed by graphite, pyrex glass and finally a NaCl sleeve.

The inclusions did not re-homogenize after the first experiment conducted at 800 °C and 10 kbar for 24 hours and, hence, it was necessary to perform a second experiment at 850 °C and 10 kbar for 24 hours. In this case almost all nanogranite inclusions were partially re-melted but some of them displayed interaction with the host garnet, such as the recrystallization of garnet around the inclusions or the crystallization of new phases (e.g., orthopyroxene) at the inclusion wall. This occurs because the trapping temperature of MI was exceeded during the experimental run. One inclusion was almost totally re-homogenized, without clear evidence of overheating. Preliminary semi-quantitative analyses have been done using EDAX system.

For the first time the composition of the melt produced by the partial melting of crustal rocks of the Valpelline Series was analysed ($SiO_2 \approx 72\%$, $Al_2O_3 \approx 13\ \%$, $K_2O \approx 6\%$, $Na_2O \approx 2\%$, $FeO \approx 4\%$, $CaO \approx 0.7\%$). This work also confirms the previous temperature estimates from the literature on peak conditions of the Variscan metamorphism.

Medium-high grade metamorphism of paragneisses and banded-amphibolites from the Seve Nappe Complex of the Kebnekaise Mountains, north-eastern Scandinavian Caledonides

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Here we present preliminary petrological study of representative samples of paragneiss and banded amphibolite from the Kebnekaise region, Seve Nappe Complex, northern Swedish Caledonides. The studied tectonic unit represents the distal margin of Baltica and bears a record of Ordovician high-pressure metamorphism along the strike of the orogen. At the outcrop scale, the banded-amphibolite displays a migmatitic texture with an alternation of amphibole-bearing mafic and garnet-bearing felsic layers. The rock reveals a mineral assemblage composed of amphibole, quartz, garnet, plagioclase, K-feldspar, titanite, epidote, biotite, rutile and zircon. A weak banding is underlined by amphibole-bearing layers, formed by amphibole + quartz + plagioclase + titanite ± zoisite and amphibole-absent layers composed of quartz + plagioclase + K-feldspar + garnet + titanite + clinozoisite. Amphibole belongs to Ca-amphiboles varying in composition between pargasite and Mg-hornblende. Particularly, its grain boundaries often have been replaced by an intergrowth of plagioclase, quartz, zoisite and biotite. Garnet is located only within the felsic layers. It forms euhedral porphyroblasts, which commonly contain inclusions of quartz. Garnet is slightly zoned and is characterized by $Alm_{51-49}Grs_{34-35}Prp_{7}Sps_{8}$ in the core and $Alm_{48-46}Grs_{37-36}Prp_{7-6}Sps_{8-9}$ in the rim.

Garnet-bearing paragneiss consists of quartz + kyanite + white mica + garnet + biotite + plagioclase + K-feldspar ± rutile ± graphite. Zircon, monazite and apatite are present as accessory phases. The rock is strongly mylonitised, S-C fabric and well-developed mica-fishes are common. Garnet forms elongated and/or skeletal grains. It has an average composition of $Alm_{78}Pyr_{16}Grs_{6-5}Sps_{0-1}$ and does not show significant internal zoning. K-feldspar, plagioclase and quartz constitute porphyroclasts surrounded by the matrix minerals. Myrmekite forms along the edges of K-feldspar porphyroclasts. Matrix plagioclase is zoned and is characterized by Ab_{80} in the core and $Ab_{>95}$ in the rim.

Garnet-hornblende Fe-Mg thermometer and garnet-hornblende-plagioclase-quartz barometer were applied to the banded amphibolite. A combination of these geothermobarometers gives preliminary pressure-temperature (P-T) estimates of 8.5±2 kbar and 750±50 °C. Conventional and trace element geothermobarometry was performed on the paragneiss. Garnet-muscovite (GM) geothermometer and garnet-muscovite-plagioclase-quartz (GMPQ) geobarometer were combined with Zr-in-rutile thermometer. P-T conditions estimated using GMPQ&GM geothermobarometers are 7.1±1.5 kbar and 614±16 °C. Rutile occurs as inclusions in the garnet as well as in the matrix. Inclusions from the garnet core yield temperature ranging from 565 to 640 °C at 7.5 kbar. Matrix rutile and inclusions from the garnet rim yield slightly higher temperatures of 620 to 650 °C at 7.5 kbar.

The preliminary results presented here, provide evidence for a medium to high-grade metamorphism experienced by the Seve Nappe Complex in the Kebnekaise region. Such P-T conditions of metamorphism are not unique for the studied tectonic unit. However, granulite-to-amphibolite metamorphism at other Seve localities is typical rather for the final stages of the metamorphic evolution, following high-pressure events. No high-pressure relicts have been found in the studied rocks so far. Hence, either the studied section of the Seve Nappe Complex in the Kebnekaise Mountains is too obliterated to preserve high-pressure relicts or it escaped Ordovician deep subduction.

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U-Pb dating of zircon from the Northern Swedish Caledonides used to investigate the tectonic evolution of oceanic terranes in Iapetus

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We use petrochronological techniques on rocks from the Köli Nappe Complex (KNC) of the Northern Swedish Caledonides, in order to investigate the tectonic evolution of terranes within the Neoproterozoic to Palaeozoic Iapetus Ocean. The KNC is part of the Upper Allochthon of the Scandinavian Caledonides, originating within the extinct Iapetus Ocean in island arc, oceanic crust or back-arc basin tectonic environments, along with terrigenous basin-fills. These elements are generally thought to have been accreted to the Laurentian palaeocontinental margin (though the accretion sequence is still uncertain), but were ultimately translated onto the Baltica palaeocontinent on the opposite side of Iapetus. In the interval between these events the KNC underwent rifting, magmatism and ductile deformation. Reconstructing the P-T-t history of these rocks will shed new light on the early development of the Caledonian Orogenic Belt during Late Proterozoic to Early Palaeozoic times, and thus provide insights into the evolution of oceanic terranes within orogenic belts globally, particularly with respect to accretionary orogenic processes and the transition to collisional orogenesis.

The regions of northern Jämtland and Västerbotten, northern Sweden preserve the most complete sequence through the KNC units within the Scandinavian Caledonides, and the units have good biostratigraphic constraints. Each nappe assemblage (the so called Upper, Middle and Lower Köli) may represent a distinct outboard terrane. The Lower Köli Nappes comprise Late Cambrian to Early Silurian volcano-sedimentary successions dominated by turbidites above Late Cambrian bimodal volcanics and succeeded by Early Silurian quartzites, carbonates and graphitic phyllites. The Lower Köli is interpreted as having oceanic arc, forearc and continental margin affinities. The Middle and Upper Köli Nappes also contain volcano-sedimentary successions spanning the Late Cambrian and all of the Ordovician. They are interpreted as having island arc, forearc and back arc affinities. Samples of metavolcanic rocks from the Lower and Middle Köli Nappes of south-west Västerbotten were collected in 2019. Metamorphism is of greenschist to lower amphibolite facies. Initial Electron Microprobe (EMP) data has been used for classical thermobarometry. The initial results from the garnet-biotite thermometer retrieved temperatures in the region of 450-480°C for two samples from the Lower Köli in Västerbotten, which fits with previous estimates of these units as within the upper greenschist facies. U-Pb isotopic and trace elements measurements of zircon via LA-ICP-MS (Laser Ablation Inductively Coupled Plasma Mass Spectrometry) was conducted at the Vegacenter Laboratory, Stockholm. Magmatic zircon from Lower Köli felsic metavolcanics in Västerbotten shows preliminary ages of 470-540 Ma, fitting with previous ages for Lower and Middle Köli volcanics in this area. At least one sample is from a unit interpreted to be part of a forearc succession. Trace element characterisation of studied zircon, and whole rock trace and major element geochemistry gives additional information on magmatic conditions, further linking ages to the tectonic context of the units.

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Eclogite-facies granitoid gneisses in the Western Gneiss Region giant (U)HP terrain, Norway: The role of water and implications for buoyancy during transient subduction of continental crust

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(U)HP metamorphic terranes are often dominated by granitoid gneisses whose physical properties must have influenced the tectonic evolution of orogens, yet their (U)HP mineralogy is usually poorly preserved. Their density (buoyancy) would have influenced their tendency to subduct and exhume. To gain insights into density evolution, bulk compositions of common granitoid gneisses and metabasic eclogites in the Western Gneiss Region (WGR) giant HP-UHP terrane, Norway, were used to generate isochemical phase diagrams and rock densities. For field examples in the WGR where metagranitoid HP mineral parageneses have survived retrogression the mineral assemblages are well reproduced by the model calculations. For all modelled compositions density shows a strong gradient between medium- and low-P facies into eclogite facies, while under eclogite facies conditions a wide P-T realm has densities that vary little, except for a sharp step at the quartz-coesite transition. Hence, if metamorphic transformations are efficient during subduction most lithologies will undergo a rapid increase in density above about 1.7 GPa. Mafic rocks become negatively buoyant with respect to mantle rocks while common granitoid lithologies achieve densities slightly less than dry mantle even under coesite-stable conditions. Hence felsic compositions would have tended to remain slightly positively buoyant with respect to the mantle unless the latter was serpentinised. However, where large mafic eclogite massifs are common they may contribute to a higher average density. Water has played an important role in the metamorphic transformations. Eclogite within the gneisses has zoned garnet with abundant amphibole and epidote inclusions in their cores, suggesting that initially dry mafic granulite experienced an ingress of water under amphibolite facies conditions prior to their conversion to eclogite. Garnets show healed fractures interpreted to result from dehydration of an amphibolite (or blueschist?) paragenesis and hydro-fracturing. The modelling also gives insights into the evolution of density during retrogression. Mafic to tonalitic compositions favour low phengite, omphacite-rich parageneses that require ingress of aqueous fluid in order to retrogress to lower density parageneses. Granitic compositions have more phengite, which decomposes and dehydrates upon decompression, so would have undergone rapid reduction in density, enhancing buoyant upthrust. However, where lack of water retarded retrogression in mica-poor lithologies, higher densities may have persisted. Water, then, plays a key role in the density and buoyancy evolution of granitoid-dominated, subducting crust. Thus, in the WGR transformation of dry, granulite metagranitoids to omphacite-garnet gneiss was associated with a substantial, prior ingress of water, but limits to water availability resulted in survival of unreacted, low-density rock volumes. The metamorphic transformations predicted by this modelling would, if efficient, have substantially increased the density of the predominant mass of felsic rocks in the WGR, but not to the extent that it could become negatively buoyant. During exhumation, the sharp density gradient in P-T space associated with feldspar formation and reduction in garnet would have enhanced buoyancy and perhaps acted to accelerate exhumation. Partial melting at this stage would have further enhanced the buoyant upthrust.

Spatial and temporal relations of high-pressure metamorphic events in the geodynamics of the Western Carpathians

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Metamorphic basement rocks in the Tatra and Vepor units mostly indicate amphibolite facies conditions, however retrogressed eclogites have been reported from several localities within the Leptyno-amphibolite Complex (LAC) rocks from these two units. The newly discovered retrogressed eclogite in the Gemer Unit allows us to clarify geotectonic relationships among major basement units in the Western Carpathians during Variscan Orogeny. The eclogite with strong amphibolite facies overprint was found as a pebble in the Upper Carboniferous conglomerates underlaying the Gneiss-amphibolite Complex (GAC) and the Rakovec greenschist facies rocks of the Gemer Unit. The eclogite facies minerals are omphacite, garnet and rutile for that peak pressure and temperature of about 2.0 GPa and 650 °C are estimated. This finding together with some retrograde textures (plagioclase + hornblende/diopside symplectites) observed in amphibolite bodies confirm that at least some of the GAC rocks underwent an earlier eclogite facies metamorphism. The Rakovec greenschist belt that extends along the northern rim of the Gemer Unit is generally accepted as a suture zone formed during Variscan Orogeny. The rocks locally bear evidences of an earlier low-temperature high-pressure metamorphism, which is supported by the presence of Na-Ca amphibole and Na-clinopyroxene.

The pressure and temperature conditions for both eclogite and subsequent amphibolite facies stages in the GAC eclogite are comparable with those reported from retrogressed eclogites in the LAC from the Vepor and Tatra units. In combination of available information on the typical lower crust lithology of the LAC and the presence of arc-related magmatism of Variscan age in the Tatra and Vepor crustal units, we discuss possible relationships of the eclogite facies metamorphism to a suture zone, along which the earlier high-pressure rocks were exhumed. In addition to formation of the eclogites, we focus on the mechanism of heat production and amphibolite facies overprint of high-pressure rocks during their exhumation. The origin of eclogites and blueschists in these units will be further discussed with respect to the high-pressure rocks occurring along the European Variscan Belt.

As the whole Gemer Unit underwent Alpine metamorphism, the retrogressed eclogites and associated gneisses were studied to clarify degree of Alpine overprint in the GAC. This younger metamorphic event is recorded by the formation of a new garnet, which overgrows or rims the older eclogite-amphibolite facies garnet. In addition to amphibolite facies fragments of the basement rocks with Jurassic blueschist facies overprint, the Alpine metamorphism occurred in most of the Gemer Unit rocks under high-pressure greenschist facies conditions. The relationships of these two processes to subduction along the Meliata suture and subsequent collisional events will be discussed.

Migration of deformation, subsidence, and basin formation in the SW Pannonian Basin and the transition to the neotectonic phase

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The Pannonian Basin is a complex extensional basin system of various depocentres within the Alpine-Carpathian-Dinaridic orogenic belt. Along the southwestern basin margin, exhumation along the Rechnitz and Pohorje-Baján detachments resulted in cooling of divers crustal segments of the Alpine nappe pile (Koralpe-Wölz and Penninic nappes); the process is constrained by variable thermochronologic data between ~22 to ~15 Ma. Fast subsidence in supradetachment sub-basins indicate the onset of sedimentation in the late Early Miocene (Ottnangian? or Karpatian, from ca 19 or 17.2 Ma). In addition to extensional structures, strike-slip faults mostly accommodated differential extension between the large low angle normal faults. This transtensional deformation also reactivated branches of the Mid-Hungarian Shear Zone.

During this time span, the distal edge of the major tilted block, the Transdanubian Range (TR), in the hanging wall of the detachment system, experienced surface exposure, karstification and terrestrial sedimentation. The situation changed after ~15 Ma, when faulting, subsidence and basin formation shifted toward NE. The propagation of normal faulting resulted in basin subsidence within the TR.

In fact, thermodynamical modelling predicted similar migration of depocenters, but on the scale of the entire Pannonian Basin. The understanding of basin subsidence chronology demonstrates this process in the SW basin part. The reason of this migration is found in the deep earth processes, like asthenopsheric flow, flattening of inherited weakness zones in the crust and upper mantle, and coeval upraisal of the astenosphere.

Simultaneously with the depocenter migration, considerable part of the former rift sytem underwent ca. N–S shortening; the basin fill was folded and the boundary normal faults were inverted. The style of deformation changed from pure contraction to transpression. The Baján detachment seemed to be slightly folded, although its synformal shape could be considered as detachment corrugation, too. The deformation was dated as Middle Badenian, ~15–14 Ma in certain basin parts while in other sub-basins deformation seems to be continuous through the entire period from ~15 Ma to ~11.6 Ma. Another pulse of contraction happened in the earliest Late Miocene, from about ~11.6 to ~9.7 Ma. All these contractional deformation can be connected to the much larger fold-and-thrust belt extending from the Southern and Julian Alps through the Sava folds region of Slovenia.

Despite that the crust was marked by shortening, the SW Pannonian area underwent the same basin-scale Late Miocene subsidence as other parts of the Pannonian Basin. This general subsidence is not governed by crustal extension, although modest Late Miocene fault reactivations are frequent. The explanation is found in the reorganisation of asthenosphere convection processes and formation of secondary convection cells.

In this study the onset of the neotectonic phase is considered when the former Late Miocene subsidence changed to positive vertical motion, which resulted in the uplift of the TR, large parts of Transdanubia and the adjacent Eastern Alps. The onset of this process was heterochronous and poorly dated, being Late Miocene in the Styrian basin and Eastern Alps, and is younger (post-7Ma, ~6 Ma?) in the Zala Basin and in the TR. This diachronism is not unequivocally connected to gradual build-up of compressive crustal stress due to Adria–Europe convergence – because such crustal stress was present from the mid-Badenian – but most likely the expression of deep lithosphere-asthenosphere processes, in combination with sediment redistribution, denudation in the uplifted areas and continuous sedimentation in the Drava and Danube basins of ongoing subsidence. Crustal-scale contractional structures are not enough to explain neotectonic deformations.

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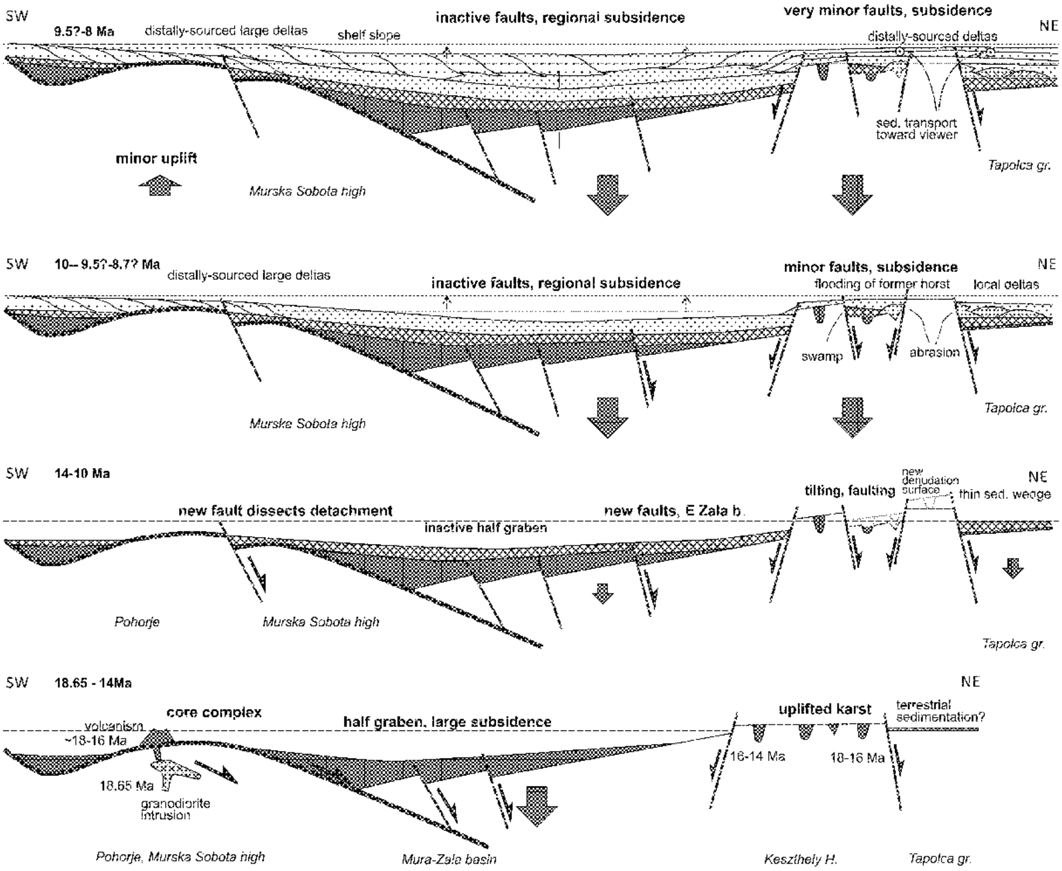

Figure 1: Schematic evolution of the SW Pannonian Basin from the Pohorje to the Transdanubian Range. Note change in locus of subsidence, faulting and denudation.

Lithospheric contact of the Western Carpathians with the Bohemian Massif in the light of seismic and gravity data

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The Bohemian Massif represents the largest exposure of rocks deformed during the Variscan orogeny. Western Carpathians form an arc-shaped mountain range related to the Alpine orogeny. In this study, the lithospheric structure and the contact zone of these two tectonic units were analyzed by 2D gravity modelling method along the NW-SE oriented CEL09 profile of the CELEBRATION 2000 seismic experiment using the new AlpArray gravity data. The resultant 2D density model based on gravity data was constrained by seismic wide-angle reflection and refraction results. Densities of anomalous bodies were defined by the transformation of the modelled P-wave velocities. A good correlation was shown between density and seismic models. The resultant 2D density lithospheric model consists of the five principal layers: sediments, upper crust, lower crust, lower lithosphere (or mantle lithosphere) and asthenosphere. In general, sediments (up to 6.5 km thick) are characterized by values from 2.30 to 2.51 $g\cdot cm^{-3}$. The non-sedimentary upper crust is split into two layers. The upper part of the upper crust is divided into various density inhomogeneities. In the Bohemian Massif these inhomogeneities largely reflect the gravity effects of the lighter granitoid plutons and metamorphic rocks (2.60-2.74 $g\cdot cm^{-3}$), together with the heavy (ultra)basic bodies (2.79 $g\cdot cm^{-3}$). In the Western Carpathians the layer consists of the crystalline mountain ranges (Malé Karpaty Mts. and Trans-Danubian range, 2.67 and 2.74 $g\cdot cm^{-3}$, respectively), and the pre-Cainozoic basement of the sedimentary basins (2.67-2.74 $g\cdot cm^{-3}$). The lower part of the upper crust is significantly more homogeneous compared to the upper part (2.78-2.80 $g\cdot cm^{-3}$). Five different sectors of the lower crust resulted from this density model, with the first sector (Saxothuringian) consisting of two separate layers. Densities in the lower crust vary from 2.85 to 3.12 $g\cdot cm^{-3}$. Depth of the Moho varies from ~30 to 38 km in the Bohemian Massif, resulting in different thicknesses in respective crustal sectors (9-19 km). The SE part of the Bohemian Massif is characterized by significant Moho anomaly, where the Moho abruptly rises from 34 km to only 28 km depth. Thickness of the Western Carpathian-Pannonian region is much more steady (10-13 km). Depth of the Moho varies from 28 km in Western Carpathians to ~31 km in Trans-Danubian range. The significantly thinned crust is shown at the end of the profile with only 25 km depth of the Moho in the Pannonian Basin. In general, the model shows the difference between the older, cooler and thicker Bohemian Massif (in average: ~32 km

thick crust, and ~120 km thick lithosphere), and the younger, warmer and thinner Carpathian-Pannonian region (~28 km crust, ~95 km lithosphere).

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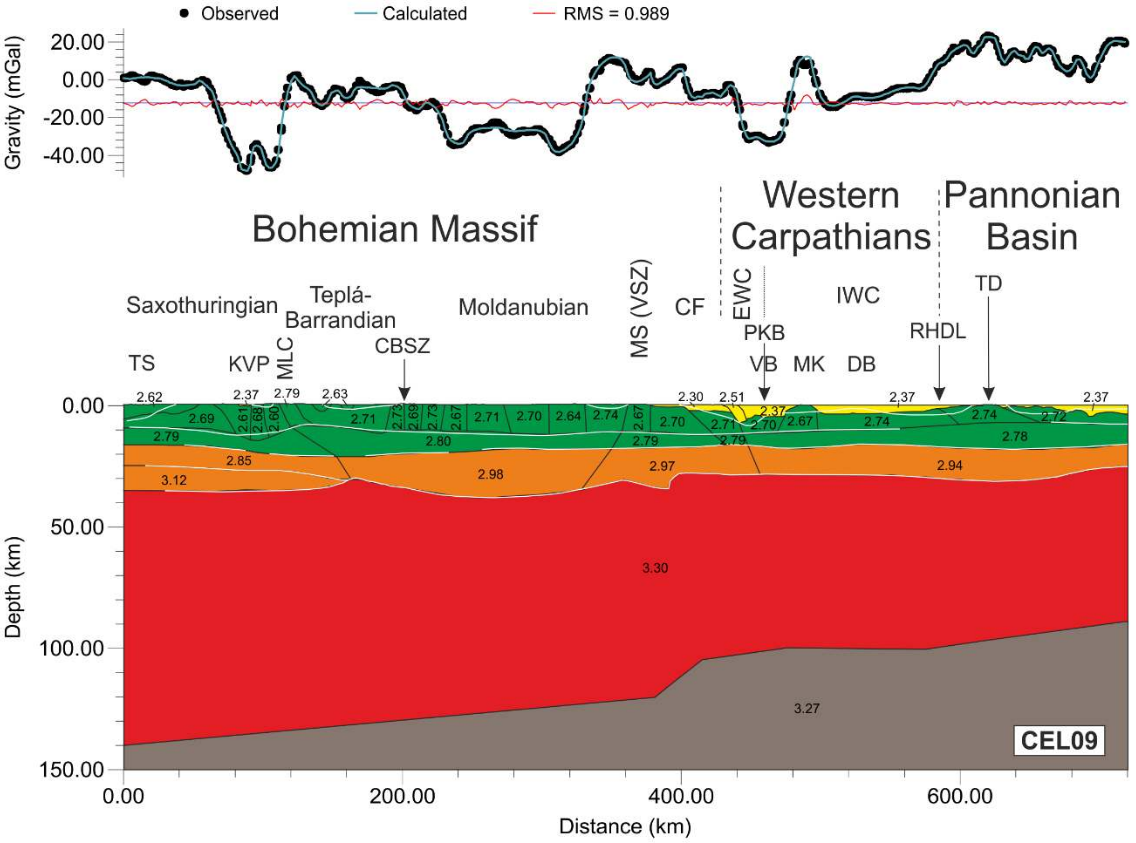

Figure 1: Resultant 2D density lithospheric model along the profile CEL09. White line represents the boundaries of the seismic model. Yellow - sedimentary cover, green – non-sedimentary upper crust, orange – lower crust, red – lower lithosphere, brown – asthenosphere, CBSZ – Central Bohemian Shear Zone, CF – Carpathian Foredeep, DB – Danube Basin, EWC – External Western Carpathians, IWC – Internal Western Carpathians, KVP – Karlovy Vary pluton, MK – Malé Karpaty Mts., MLC – Mariánské Lázně amphibolite Complex, MS (VSZ) – Moravo-Silesian (Vitis Shear Zone), PKB – Pieniny Klippen Belt, RHDL – Rába-Hurbanovo-Diósjenö lineament, TD – Trans-Danubian range, TS – Teuschnitz syncline, VB – Vienna Basin.

Timescale of pervasive melt migration in the continental crust

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Movement of a large volume of granitic melt is an important factor in the compositional differentiation of the continental crust and the presence of melt in rocks profoundly influences their rheology. Different mechanisms controlling melt migration through crust were proposed. We suggest that pervasive melt flow, analogous to reactive porous melt flow in mantle, could be possibly one of them. It is generally accepted that migration of felsic melts in continental crust starts with short distance pervasive microscopic flow into segregation veins which extract melt. However, we show that pervasive melt flow may be a regional mode of melt migration in continental crust. In such scenario, melt driven by deformation passes pervasively along grain boundaries through the whole rock volume. And the term pervasive melt flow is used for grain-scale, diffuse, porous and reactive flow of felsic silicate melt through rocks. This is effectively an open-system process that thoroughly reworks the resident rock mass. Through-flow of melt destroys pre-existing fabrics and the original chemical and isotopic nature of the protolith. Melt segregation is inefficient and protolith become isotropic granite-like, with partly preserved relics of the original, without ever containing more than a few melt percent at any time. This mode is favored by rocks of low strength and low mechanical anisotropy, as well as homogeneous deformation and low melt pore pressure, which inhibit melt segregation. In our view, pervasive melt migration may be a common though cryptic mechanism, capable of obliterating the original character of pre-existing rocks giving rise to isotropic granites. The fabric and geochemical nature of these granites encapsulates the complex history of hybridization. The porous flow of silicate melts in continental crust is a process which can operate over a long time and impacts on the rheology of the crust during orogeny. Pervasive melt flow is slow and possibly sustained over millions of years, as exemplified by the Bohemian Massif where this process lasted up to10 m.yr. In order to demonstrate the extensive timescale of such pervasive melt migration we present precise U-Pb monazite ID-TIMS (isotope dilution thermal ionization mass spectrometry) and U-Pb monazite Laser Ablation Split Stream (LASS) geochronology in combination with monazite chemistry as well as U-Pb zircon SHRIMP geochronology.

Features related to destabilization of magmatic labradorite with increasing metamorphic grade of metagabbros from the west of the Teplá-Barrandian Unit, Bohemian Massif

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Small isolated bodies of metagabbro are located along the contact of Mariánské-Lázně and Teplá Crystalline Complexes (NW of the Bohemian Massif) and intruded this area during Cambro-Ordovitian rifting event (c. 500 Ma). All studied samples show well preserved magmatic texture defined predominantly by plagioclase - clinopyroxene – orthopyroxene – amphibole - ilmenite ± olivine ± biotite grains. During Variscan deformation gabbros were metamorphosed in amphibolite-facies conditions (up to c. 710°C; 14 kbar). The metamorphism is characterized by 1) formation of multilayer coronas at the contact of plagioclase with other minerals, the newly formed metamorphic phases involve orthopyroxene, amphibole and garnet; 2) breakdown of magmatic plagioclase reflecting the degree of metamorphic changes, which is the subject of this study. The metagabbro samples contain magmatic plagioclase forming large grains of up to 3 mm size, which usually preserve original labradorite composition in central parts. Across the studied samples we can demonstrate progressive breakdown of magmatic labradorite and its effect on plagioclase recrystallization. In initial phases plagioclase breakdown occur in domains located at marginal parts of the large grains, where the original grain is replaced by a mixture formed by thin elongated lamellae of anorthite-bytownite (An83-91) with apparent random orientation enclosed within oligoclase-andesine (An27-48). With ongoing metamorphism the breakdown of labradorite occur in the whole volume of the plagioclase grains. In case of sample that reached highest metamorphic conditions and show evidence of deformation, the texture typical for other samples is transformed into fine-grained recrystallized grains with compositional zoning defined by increasing anorthite content from core (An35-46) to rim (An79-94). Additionally, in the non-deformed samples, corundum lamellae of thickness bellow 1 μm with visible preferred orientation are often observed as well as tiny spinel grains forming chain-like texture or isolated grains are present here. In order to get constrains on the processes responsible for such chemically and texturally complex plagioclase decomposition, the previously characterized domains were studied with the method EBSD in order to determine the crystallographic orientation of the observed phases and examine their possible relations. In the samples representing initial stage of the plagioclase breakdown, both calcic and sodic plagioclase share the crystallographic orientation with their parental labradorite, which is interpreted as a product of an exsolution process. This process possibly started during increasing PT metamorphic overprint when some metastable plagioclase domains were juxtaposed to fluid and the plagioclase started to breakdown due to an immiscibility gap in its composition. In given metamorphic temperature that is considerably lower than the temperature of magmatic plagioclase crystallization. In the samples showing more advanced stage of the breakdown, partial recrystallization can be observed in form of appearance of new sub-grain boundaries formed in the central parts of the Ca-rich lamellae. With ongoing deformation, these domains are then separated from the parent crystal and appear as individual grains while maintaining their inherited compositional zoning with Ca increase from core to rim.

The study of the crystallographic relation of the Al-rich phases (spinel and corundum) show that spinel crystallographic orientation is controlled by the crystallographic orientation of the host plagioclase, while corundum lamellae show relations with the host plagioclase orientation only in several directions. The formation of spinel and corundum is interpreted as a result of variable diffusion rates of Ca and Al from the plagioclase during the corona formation.

Geochronological, geochemical and petrological constrains on magmatic and metamorphic evolution of the metagabbros from the Western part of the Teplá-Barrandian Unit, Bohemian Massif

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Teplá-Barrandien Unit is a segment of dominantly unmetamorphosed and weakly metamorphosed rocks representing the orogenic upper crust of the Variscan orogeny in the Bohemian Massif. Its westernmost part is characterized by increase in the metamorphic degree up to amphibolite or eclogite metamorphic conditions at the contact with the rocks of the Moldanubian and Saxothuringian domains. Along this western border, numerous intrusions of dominantly gabbroic rocks affected by various degree of metamorphism are present.

This study is focused on petrographic, geochronological and geochemical characterization of these (meta)gabbroic rocks that are located in two areas: 1) the contact of the Teplá Crystalline (TCC) and Mariánské Lázně (MLC) complexes in the NW corner of the TBU, 2) in area between the Domažlice Crystalline Complex (DCC) and Kdyně-Neukirchen Massif (KNM) in the SW part of the TBU. Such a study can provide constrains on the pre-Variscan and Variscan evolution of western margin of TBU. All representative samples show well preserved magmatic texture with primary mineral assemblage (plagioclase – orthopyroxene – clinopyroxene – amphibole – biotite − ilmenite ± olivine ± spinel ± quartz). The metamorphism is reflected by the formation of single or multiple coronas at the contact of plagioclase with other primary minerals, most significantly with olivine and orthopyroxene. The corona sequences generally consist of orthopyroxene and amphibole (cummingtonite, actinolite and/or hornblende), occasionally with spinel. In olivine-free samples from MLC-TCC corona sequences are commonly terminated by a garnet layer. Additionally, breakdown of magmatic plagioclase was documented in samples from the TCC-MLC, progressive breakdown of the magmatic plagioclase is reflected by the formation of mixture An_{40} and An_{90} plagioclase associated with spinel, corundum and occasionally kyanite.

Comparison of trace element characteristic of the studied samples shows that the TCC-MLC samples have N-MORB character (with exception of olivine cumulates), while geochemical record in DCC-KNM is more complicated. Samples from KNM area have relatively lower content of REE and immobile elements compared to the TCC-MLC samples, while the DCC samples are enriched in all these elements compared to the TCC-MLC samples. This can be explained by cumulative character of the KNM samples and higher amount of assimilated surrounding rocks in DCC samples. However, similar Sr and Nd isotopic ratios in all samples implies that gabbroic rocks from both areas (TCC-MLC and DCC-KNM) probably share the original magma source. Representative samples were used for U-Pb zircon dating.

Across the samples, zircons occur as isolated metamictized grains which yield similar mean age c. 500–510 Ma in both areas, DCC-KM samples also show minor peak age at c. 520 Ma. Zircon in both areas also forms thin rims around ilmenite and these grains yield age c. 480–490 Ma which points to late-magmatic origin of this feature. The only Variscan (c. 360–380 Ma) ages were obtained for zircon corona around baddeleyite observed only in TCC-MLC samples.

Although there are similarities in corona sequences in samples from both areas, it is also important to point out some differences. Corona sequences in samples from TCC-MLC usually contain layer with symplectitic texture (plagioclase-amphibole/plagioclase-orthopyroxene) and kyanite is commonly present as inclusion in garnet corona. On the other hand, more amphibole varieties are observed in corona sequences in DCC-KNM, especially occurrence of gedrite suggest high temperature metamorphism. Together with estimated PT conditions, it is demonstrated that each area was metamorphosed in different field gradient, where TCC-MLC area suffered by higher P and lower T compared to DCC-KNM area. Samples from TCC-MLC area experienced Variscan metamorphism under amphibole-facies conditions, but there is no strong evidence for such significant reequilibration during Variscan event in DCC-KM samples, thus there is reason to believe that coronas in DCC-KM samples were developed by autometamorphism during retrogression from granulite-facies conditions. If we take into account isotopic data and geochronological results it is likely to consider that both studied areas are part of one intrusion complex, where KNM area represents magmatic complex formed by assimilation of fractional crystallization, DCC can be interpreted as the upper part of the intrusion more affected by assimilation of surrounding rocks and TCC-MLC gabbros characterize more mature magma subsequently metamorphosed during Variscan orogenic event.

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U-Cu mineralization in the Kozie Chrbty Mts. (Permian, Hronic Unit) and its relationship to the late (neotectonic) structures

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Stratiform U-Cu mineralization (0.02-1.13 % U) in the eastern part of the Kozie Chrbty Mts. (also Dúbrava Mts., Vikartovský chrbát Mts, respectively) is bound to the Permian volcano-sedimentary complex of the Ipoltica Group, Hronic Unit (Western Carpathians). The wide surroundings of the deposits are formed by other, Triassic sediments of Hronic Unit (mainly limestones, dolomites, quartzites and shales) also by Paleogene sedimentary complexes of the Podtatranská Group (sandstones, conglomerates, claystones). The ore deposits (Vikartovce, Kravany, Švábovce, Spišský Štiavnik) are situated in the arcosic sandstones of the Upper Permian part of the Kravany beds with carbonized fragments of higher plants. The deposits were exploited during the survey (60s – 70s of the 20th century).

Relatively late tectonic events affected the volume and the quality (and also minig-technical conditions) of considered ore deposits. This tectonics resulted in irregular distribution of mineral ore in this region. In the western part of the Dúbrava Mts. (Vikartovce, Kravany deposits), the distribution of the ore is relatively regular, limited to 1 – 2 ore bearing horizons. In this case, the structure of the deposits is limited mainly by Vikartovce Fault with subvertical sence of movement. On the other hand, the Švábovce deposit features 6 ore bearing horizons.

Concerning the tectonic condition, Kravany and Vikartovce deposits (western part) are situated to the north (in the bedrock block) and in close proximity (200 – 300 m) of Vikartovce Fault of east-to-west direction. On the contrary, the Švábovce and Spišský Štiavnik deposits (eastern part) are located on a neotectonic structure that limits Dúbrava Mts. from the north (W-E direction). The Kravany and Vikartovce deposits are disrupted by disjunctive tectonics in two directions: faults east-to-west causing 5 – 10 m declines of southern blocks faults, and faults with northeast-to-southwest direction causing 10 m declines of southwestern blocks. The deposit conditions on the eastern part of the Dúbrava Mts. are limited by the combination of the neotectonic fault systems: Vikartovce, Gánovce and Muráň-Divín.

At the Kravany deposit, local tectonic caused the formation of so-called „zone ore mineralization“ (a similar is known on the Novoveská Huta U-Mo deposit), when U-Cu mineralization occurs in the tectonic zone (reprocessed carbonized plant residues, uraninite, pyrite, chalcopyrite and carbonates).

Stratiform, infiltration U-Cu-Pb mineralization in the eastern part of the Vikartovský Chrbát is bound to the Upper Permian clastic sediments (Kravany beds, member of Malužiná Formation, Hronic Unit). Their lithological composition is represented by green to dark gray fine to medium-grain arcosic sandstones, locally by arcoses, gray-black sandstones and siltstones with a significant content of carbonized plant debris. Uranium mineralization together with Cu and Pb mineralization are concentrated mainly in the cracks and pores of carbonized organic matter. Stratiform U-Cu-Pb mineralization is represented by minerals: uraninite, coffinite, U-Ti oxides accompanied by arsenopyrite, chalcopyrite, pyrite, marcasite, tetrahedrite, tennantite, galena, sphalerite, quartz, calcite and dolomite. The age of stratiform mineralization was set at 263 – 274 Ma, based on U-Pb dating.

Secondary minerals described in the supergene zone of U ore deposits are uranophane, autunite, torbernite, metatorbernite, azurite, malachite, arsenopyrite, goethite, limonite, covellite, chrysocolla, gypsum and zálesíite.

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On the origin of similar magnetic fabrics in crystalline rocks of the Silesicum and sedimentary rocks of the Rhenohercynian Zone of the NE Bohemian Massif

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The sedimentary rocks of the Lower Carboniferous accretionary prism of the Rheno-Hercynian Zone (RHZ) of the NE Bohemian Massif, represented by the Nízký Jeseník Mts., show very variable mesoscopic and magnetic fabrics. In the easternmost Hradec-Kyjovice Fm., the achimetamorphism and ductile deformation are very weak; the degree of AMS is also weak, the magnetic fabric is oblate, the magnetic foliation is either parallel to the bedding or tends to create a partial girdle in its poles. The strata create buckle folds of long wavelength whose magnetic fabric can be unfolded geometrically. The magnetic fabric then corresponds to *Sedimentary Fabric* or to *Incipient Deformation* stage. In the central Moravice Fm., spaced cleavage and relatively tight buckle folds can be found. The degree of AMS is higher and the magnetic foliation is still mostly parallel to the bedding, but the magnetic lineation is re-oriented into parallelism to the cleavage/bedding intersection lines. The magnetic fabric of the most folds can be unfolded only partially. The magnetic fabric corresponds to the *Pencil Structure* and *Weak Cleavage* stages. In the western Benešov and Andělská Hora fms., cleavage folds and very well developed slaty cleavage occur. The degree of AMS is high, the fabric is oblate, the magnetic foliation is parallel to the slaty cleavage and the magnetic lineation is parallel to the cleavage/bedding intersection lines. The magnetic fabric in the folds is homogeneous, the folds cannot be unfolded at all. The magnetic fabric then corresponds to the *Strong Cleavage* stage. In the westernmost area of the Andělská Hora Fm., one can observe only one system of fissility planes, because the slaty cleavage is transposed into the metamorphic foliation. The crystalline complex of the Silesicum of the Hrubý Jeseník Mts., westerly neighbouring the RHZ prism, is represented by various metamorphic rocks, such as slates, gneisses, quartzites, amphibolites, and by granitic rocks. The metamorphic rocks vary from Precambrian to Devonian in age, the granitic rocks are partly older than Late Palaeozoic, partly Late Palaeozoic in age (the Žulová Massif). Surprisingly, the metamorphic rocks and the older granitic rocks, though exhibiting variable different ages and metamorphism grades, show similar orientations in both magnetic foliations and magnetic lineations. In addition, their orientations of magnetic fabrics are very similar to those of the rocks of the RHZ wedge.

Similar magnetic fabric orientations in the RHZ prism and in the Silesicum can be explained by assuming that all the above magnetic fabrics originated during one metamorphism and deformation process associated with the Devonian-Carboniferous subduction. The eastern Hradec-Kyjovice Fm. and partly also central Moravice Fm. keep their sedimentary magnetic fabric only weakly affected by ductile deformation. The relatively strong ductile deformation and anchizonal metamorphism in the western Benešov and Andělská Hora fms. suggest that the rocks of these formations were probably buried relatively deeply. This burial may have taken place during the passage of the sediments to the inlet of the subduction zone and the sediments may have appeared at the surface due to return flow. The Silesicum may have initially served as the back stop for the RHZ prism. Later, it may have been detached from the upper plate and dragged to the subduction zone inlet. Its rocks may have suffered partial retrogressive metamorphism (existence of transverse micas) and strong ductile deformation coaxial with that suffered by the western RHZ rocks. In this deformation, the older metamorphic fabrics may have been strongly overprinted to obliterated. Finally, the rocks may have appeared at the surface through return flow.

Cryptic crustal growth in European Variscan orogen: evidence from ultrapotassic plutonic rocks of the Bohemian Massif

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The sources, genesis and geodynamic causes of specific Early Carboniferous ultrapotassic magmatic activity in the Moldanubian Zone represent one of the most intriguing questions in the geological history of the Bohemian Massif. Both the nearly contemporaneous durbachite (strongly porphyritic Amph–Bt quartz syenite–melagranite – e.g., Třebíč or Milevsko/Čertovo Břemeno plutons) and syenitoid (essentially equigranular Bt–two-Px quartz syenite–melagranite – Tábor and Jihlava plutons) suites share nearly identical whole-rock chemistry. Characteristic are high mg#, transition elements contents and mantle-like Mg isotopic signatures (most δ^{26}Mg = –0.20 to –0.35 ‰, centered at –0.25 ‰) on one hand, as well as strong enrichment in lithophile elements (Cs, Rb, K, Th, U, Pb, Li) and their crustal-like isotope ratios (^{87}Sr/^{86}Sr$_{337}$ = 0.710–0.713, $\varepsilon^{Nd}{}_{337}$ = –6.5 to –8.0, ^{206}Pb/^{204}Pb$_{337}$ ~ 17.8–18.3, ^{207}Pb/^{204}Pb$_{337}$ ~ 15.5–15.6, ^{208}Pb/^{204}Pb$_{337}$ = 37.8–38.3, δ^{7}Li mostly ~ –2 ‰ to +2 ‰) on the other. Lastly, the δ^{18}O values span a broad range from mantle- to crustal-like (*c.* +6 to +10 ‰) compositions.

The current petrogenetic model assumes a deep subduction of the predominantly felsic metaigneous Saxothuringian slab, polluting the originally depleted (harzburgitic) lithospheric mantle either directly, or via slab-derived (U)HP melts/(supercritical) fluids. Regardless of its exact mechanism, this ‘orogenic mantle metasomatism’ is thought to have produced peculiar rock types within the lithospheric mantle, such as garnet clinopyroxenites, phlogopite harzburgites or glimmerites.

A spectacular direct proof for interaction between the deeply subducted crust and the overlying mantle wedge has been provided by the recent study of the University of Potsdam on polycrystalline inclusions hosted by eclogite layers within mantle peridotite slivers of the Saxon Granulite Massif. Likewise, from the Blanský les granulite massif were described multiphase solid inclusions within phlogopite–garnet harzburgite as relics of a fossilized LILE-rich carbonated potassic silicate melt, derived from partial melting of subducted metapelitic sediments.

After a rather short incubation time, a heat pulse at ~340 Ma, possibly connected to slab-breakoff, or *in-situ* radiogenic heat production within relaminated felsic metaigneous crust, may have triggered widespread partial melting of the phlogopite-bearing metasomes. This process would yield LILE-rich primary ultrapotassic magmas with mixed mantle–crustal whole-rock geochemical and isotopic signature. Only the syenitoids seem to have developed by essentially closed-system fractional crystallization ± crystal accumulation of mainly Cpx

± Opx and Phl. However, in the durbachite suite, the source-derived signal has been further masked by crustal contamination/hybridization by anatectic melts, that seems almost unavoidable during the magma ascent through a hot collisional orogen. In any case, the slab-derived Sr–Nd isotopic signature, swamping the metasomatized mantle source to the ultrapotassic mafic magmas, was more evolved than that of the relevant mid–lower crustal lithologies of the Moldanubian upper plate. This resulted in highly unusual mixing arrays observed in the durbachite suite, such as the negative correlation of MgO with initial epsilon Nd values.

The described in-source contamination of the lithospheric mantle source to the ultrapotassic primary magmas precludes conventional detection and quantification of such contaminated mantle contribution to orogenic magmatism and related crustal growth, e.g. using Nd or Hf isotopes. Such a "cryptic crustal growth" could result in gross underestimation of the mantle-derived input in parts of the European Variscan orogen, and elsewhere. This may call for revision of the current terminology to include crustal recycling via 'dirty' mantle and (ultra-) potassic partial melts derived therefrom.

In fact, the fate of individual elements, in particular contributions from the harzburgitic depleted mantle (potentially also the intervening asthenospheric mantle), lower plate (in-mantle crustal contaminant) and upper plate crust need to be assessed separately. This requires developing new geochemical tracers for studies of elemental fluxes accompanying the crustal recycling/growth. One possible avenue seems to offer non-traditional isotopes of mantle-compatible trace elements.

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Zircon geochronology of the Sudetic portion of Teplá-Barrandia: protolith ages, provenance and significance as source rocks for Devonian and Carboniferous sedimentary basins

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In the Bohemian Massif, tectonothermal evolution of centrally located units (Teplá, Márianske Lázne) terminated before the end of the Devonian. Similar feature characterizes the Góry Sowie Massif, Kłodzko Metamorphic Massif and Sudetic ophiolite suite in the Sudetes. Paleogeographically, all these units are assigned to Teplá-Barrandian (Bohemia) domain, a part of the Armorican terrane assemblage. The uplifting Sudetic units were emerging from the Saxothuringian Ocean and immediately flanked on the south and north by (par-)autochthonous sedimentary basins in which detrital material and carbonate started to accumulate as early as in Frasnian/Famennian times.

To shed more light on the pre-Variscan magmatism and paleogeography, new LA-ICPMS studies were performed of zircons retrieved from: (1) paragneisses, migmatites and metabasites on the Góry Sowie Massif, (2) slates of the Kłodzko Metamorphic Massif, (3) Devonian sandstone olistolith in the Bardo Basin and (4) Carboniferous melange in the Kaczawa Succession being fragment of the Saxothuringian Ocean.

In sillimanite-biotite paragneisses of the Góry Sowie Massif, detrital zircons revealed mainly Neoproterozoic ages and the maximum depositional ages of ~540-550 Ma, which suggested that the sedimentary protolith accumulated in post- Ediacaran times. The second important age cluster contains Palaeoproterozoic-Neoarchean ages, while detrital zircons dated at 1.2 to 1.5 Ga and possibly metamorphic zircon dated at ~390 Ma occur very rarely. Migmatite and metabasite sampled in the Piława area of the Góry Sowie Massif contain normal prismatic zircons which provided a predominant age cluster of ~500 Ma, being interpreted as the age of their igneous protoliths. The concordia age of ~382 Ma calculated for 10 youngest zircon analyses in the amphibolite sample is consistent with the time of regional metamorphism in the Góry Sowie complex.

On the basis of oxygen isotope composition single grains methodology on SHRIMP it was documented that grains from metabasite have a bimodal oxygen isotope distribution, with values in range 4.92 -8.10‰, that evident a cluster of grains (10/30 grains) crystallizing from the mantle melt accompanied with contribution of mildly evolved crustal magmas. Whereas zircons hosted in migmatite are characterized by lack of grains with δ^{18}Ozrn mantle signature and values only in range of 8.14- 11.29‰, which are mostly higher than that of I-type granitic melt (<8‰). It tentatively suggests solely supracrustal source.

Except for the metamorphism in Middle/Late Devonian times, the obtained protolith ages and detrital zircon spectra for the Góry Sowie rocks show similarities to those known from the Sudetic units belonging to the Saxothuringian realm, for instance the Karkonosze-Izera Massif and the Orlica-Śnieżnik Dome that occur on either side of the centrally located Góry Sowie Massif, the latter affiliated with the Teplá-Barrandia (Bohemia) domain.

In the Kłodzko Metamorphic Massif, slates of the possibly youngest lithostratigraphic element contain detrital zircons that revealed Middle Devonian (with the maximum depositional age of ~384 Ma), Cambro-Ordovician, Neoproterozoic and Paleoproterozoic age clusters. The most likely source of the detrital zircons could be the metamorphic edifice of the Góry Sowie Massif that was uplifting and exposed nearby.

U-Pb dating of detrital zircons coming from the allochthonous part of the Bardo Succession (olistolith of Devonian sandstone) reveals some similarities to the zircon age spectrum in the Kłodzko Metamorphic Massif. 80% of detrital zircons represent Early Palaeozoic (between 410 and 370 Ma), the other zircon maxima are at c. 500 Ma, between 580 and 620 Ma, some between 2.0 and 3.3 Ga, and one analysis gave 1.1 Ga. A Devonian olistolith in the Carboniferous melange of the Kaczawa Succession displays the similar range of zircon ages, with even higher content of Early Palaeozoic zircons, which amounts to ~90% of the concordant zircon ages.

An integration of our new geochronological zircon data with those published so far indicates that the Early Paleozoic sedimentary basins later built in the studied Saxothuringian and Teplá-Barrandian (Bohemian) units were all supplied from similar pre-Variscan sources. In the NE Teplá-Barrandia, ~500 Ma igneous event gave intrusions of felsic and mafic magmas, generated mainly in the crust and mantle, respectively. From the Late Devonian the Teplá-Barrandian (Bohemian) microplate was eroded and delivered detritus to adjacent basins. It also appears from our and the hitherto published provenance studies that ~380 Ma old zircons seems to be over-represented in sedimentary rocks deposited both in the Variscan hinterland and foreland basins. In the Variscan orogen of central Europe, the exposed surface area of the Tepla-Barrandia domain in Late Devonian-Early Carboniferous times must have been significantly larger than the today outcrop extent and shed clasts to the basins that existed between the Armorican terranes.

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Geochronological constraints on the deformation of the metasediments surrounding high-grade rocks of Erzgebirge Mts. (Saxothuringian unit, Bohemian Massif)

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The metasediments surrounding the Erzgebirge crystalline complex (Saxothuringian unit) remain scarcely studied, although they well-preserved the record of Variscan structural and metamorphic evolution. Detailed geochronological (monazite U-Pb and mica ^{40}Ar–^{39}Ar dating), structural and petrological investigations were performed along three cross-sections from low-grade phyllites to high-grade micaschists and gneisses. Three distinct tectonometamorphic events have been identified: 1) formation of the accretionary wedge under HP-LT conditions (16 kbar, 480°C), 2) exhumation and ductile thinning of the wedge (9 kbar, 610°C) and 3) late shortening and folding. The early S1 fabric reflecting accretionary wedge architecture is preserved in low-grade phyllites, and it is progressively transposed to secondary sub-horizontal metamorphic foliation S2 towards the structurally lower micaschists. Here the fabric is developed under MP-MT M2 metamorphism. The last deformation event D3 is manifested by post-metamorphic upright folding with ENE-WSW trending fold axes.

Nine samples representing individual metamorphic fabrics have been analyzed by *in-situ* monazite geochronology with laser-ablation split-stream inductively coupled plasma mass spectrometry allowing to obtain REE composition from the same measured spot. Monazites are mostly discordant and a common Pb correction was applied to give the following ages. In phyllites, there is a prominent single group of ages around 350 – 340 Ma. In micaschist samples that have strong S2 metamorphism, there are two groups of ages and REE paterns. The monazites located in the recrystallized M2 matrix or included in the rim of garnet were dated to 330 Ma, while few grains in the locally preserved domains of high-pressure matrix M1 or enclosed in the garnet core are older, around 340 Ma. ^{40}Ar–^{39}Ar geochronology on micas was used to date 16 samples using step-heating and *in-situ* UV-laser ablation. The results are consistent with the monazite dating. The northern phyllites preserve older ages spreading between 343-328 Ma, while in micaschist the ages cluster close to 330 Ma. The whole geochronological results allow us to associate the HP event in phyllite and micaschist units to 350 – 340 Ma, corresponding to the formation of the accretionary wedge. Later, the micaschists experienced a strong metamorphic overprint around 330 Ma corresponding to the development of the MP-MT fabric S2, interpreted as the exhumation and thinning of the wedge. The late folding is manifested by the youngest Ar-Ar ages in phyllites and micaschists, around 330-325 Ma.

Two-phased folding in the Nagyvisnyó area, NW Bükk Mts., NE Hungary

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Although, the geological evolution of Hungary is quiet well known, there are still a lot of unknown and not well understood geological features in the Bükk Hills. In the past decades, the Hungarian geologists gave more attention to its lithological and structural evolution but many questions remained unanswered.

Hence, I carried out some research in the surroundings of Nagyvisnyó which is located in the NW-Bükk Mts. (NE Hungary). In this study, I focused on the observation of the outcrop-scale structural features and I attempted the interpretation of their development. I did field measurements in five different outcrops where I observed several types of faults and folds. Some of these folds had outcrop-scale till few of them map-scale sizes. After the comparison of my results to previous studies, I could restore the structural evolution for this area. Six different deformation phases were separated, in which there are even two different sets of folds, which may be attribute for the major deformation event of the Bükk related to the Cretaceous nappe stacking and subsequent thrusting and folding. Moreover, the N-S striking folds have not discovered/observed at all in this area before. Still the NE-SW striking folds seem to be more important than the N-S striking sithence part of these folds are showing top to the north vergence and the other part top to the south vergence. Top to the north vergence folds were observed along the Nekézseny thrust zone by Éva Oravecz, what indicates the two areas might have structural connection.

By restoring the local deformation history in the Nagyvisnyó area, we are able to better understand the structural evolution of the Northern Bükk Hills and its connection to the Uppony Hills.

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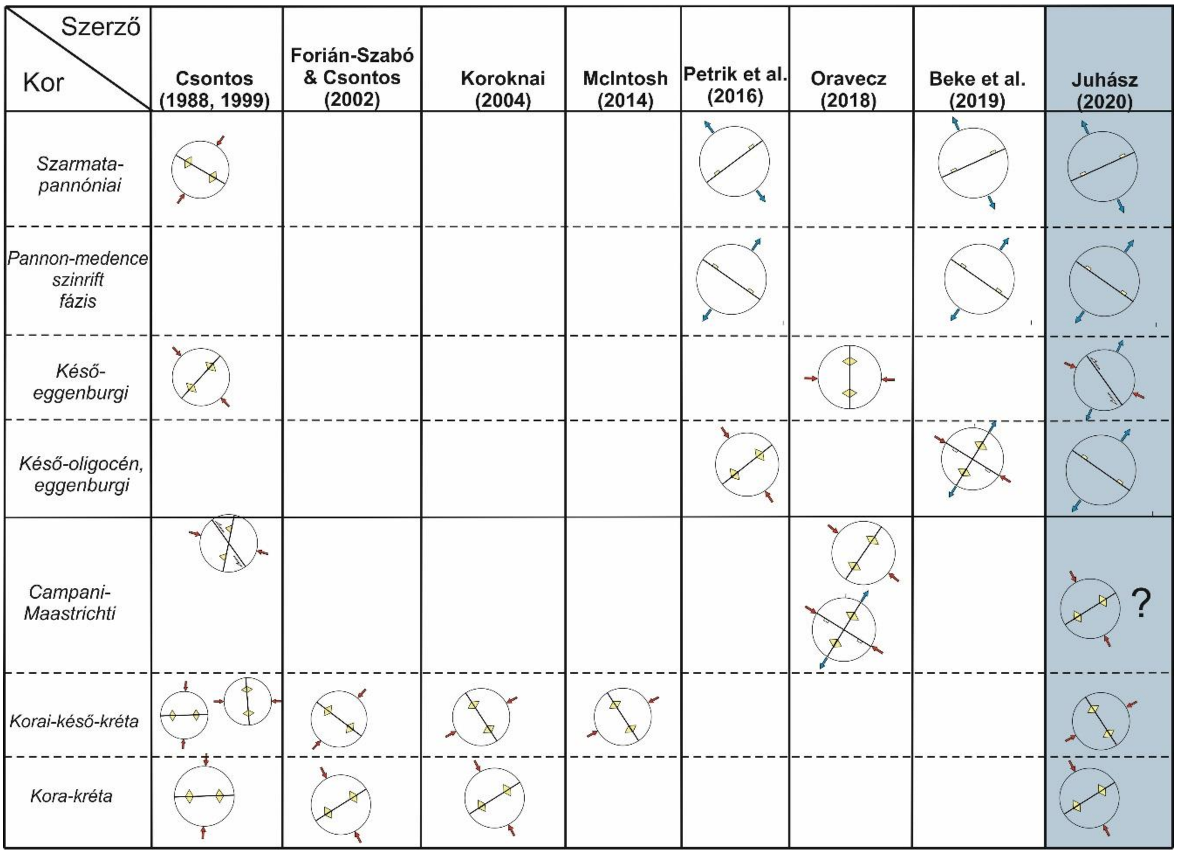

Figure 1: The six different deformation phases separated by me (the blue column) and compared with previous studies.

Archaeometry of greenschist Neolithic polished stone tools from Northeast Hungary

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Four polished stone tools were identified as greenschist lithotype in the archaeological collection of the Herman Ottó Museum. The archaeological locality of the implements is Borsod-Derékegyháza (Edelény) (inventory numbers: 53.160.18; 53.160.21; 53.160.143) and Miskolc, Airport, sand mine (inventory number: 67.3.76). The implements from Borsod-Derékegyháza belong to the Middle Neolithic Bükk culture, and the implement from Miskolc relates to the Alföld Lineary Pottery Culture or Bükk culture.

Macroscopically the tools are fine-grained and foliated. Their colour is green, green and white bands can be studied on their surface by naked eye. Magnetic susceptibility value varies between $0.43–1.21*10^{-3}$ SI. Bulk chemistry was performed on the samples 53.160.18; 53.160.21 and 67.3.76 by the non-destructive prompt-gamma activation analyses (PGAA). In the TAS diagram, their bulk chemistry data plot in the basalt field and having subalkali characteristic and in the AFM diagram, the samples have tholeiitic affinity.

Chemical analyses (EDS/SEM) were carried out on all samples. 67.3.76 was analysed from polished section, while the others were measured on their original surface. The typical mineral assemblage of the greenschist implements are actinolite ± magnesio-hornblende ± winchite + albite + epidote/clinozoisite + clinochlore + titanite. XRD analyses were performed on the sample 53.160.21 and it also confirmed the mineral assemblage revealed by EDS/SEM.

Domino/Theriak thermobarometric estimation was performed on the 67.3.76 sample. First, the chemical composition was calculated based on the modal proportions of the mineral phases and compared to the bulk chemistry of the sample. The result was accepted for a correlation coefficient above 0.95. The chemical composition of the 67.3.76 sample with excess water and excluding the Ti-phases is Si(2631) Al(819) Fe(375) Mg(509) Ca(647) Na(126) O(8200) H(900) O(450) (expressed in mols). The wide P-T range computed using the stable mineral paragenesis was further specified by the amphibole and plagioclase concentration data. The modelled mineral assemblage and the intersection of the two isopleths revealed an equilibrium P-T of 3.7 kbar and 430 ºC. Due to its schistosity, greenschist is usually not a durable raw material, so it is uncommon in the polished stone collection. Consequently, it is supposed, that the possible provenance field is in the nearby area.

In the northern, eastern and central parts of Gemericum, metabasites suffered a greenschist facies metamorphism. Their P-T values cover 3–5 kbar and ~450 °C, matching our estimated data well.

In the Gemericum the Na_2O-content of the actinolite is 0.10–0.80 wt% which fits well to the 0.13–0.70 wt% Na-content of actinolites detected from the implements with no winchite in them. Furthermore, winchite-bearing greenschist was also described from the central part of the Gemericum. Unfortunately, there are no bulk chemistry data of the Gemericum greenschists to be able to compare our results with them.

Greenschists are also known from Felsőcsatár, from West Hungary, which is much further away from the archaeological localities than the Gemericum outcrops. However, the mineralogical assemblage is very similar to the Slovakian ones and to the stone implements. In the surroundings of the Carpathian Basin significant greenschist occurrences are known in the Apuseni Mountains (Romania) too, but the comparison could not be carried out due to the lack of mineralogical and petrological data from that territory. Based on the mineralogical and thermobarometric data and the low amount of the greenschist polished stone tools in the archaeological collection of the museum, the assumed provenance field is the Gemericum, South Slovakia.

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The Variscan granitic magmatism of the Western Carpathians: Evolution within the subduction and collision stages

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Genesis of the granitic rocks – acid, felsic igneous rocks that crystallized from magma is mostly related to subduction and collisional processes, where melting process require middle- to lower crustal P-T condition. The Western Carpathians as a part of Stille's Neo-Europa form a piece of an extensive, equatorial Alpine orogenic belt. The present-day structure of the Western Carpathians was derived from the Late Jurassic to Cenozoic (Alpine) orogenic processes connected with the evolution of the Neo-Tethys Ocean, in a long mobile belt sandwiched between the stable North European Plate and continental fragments of the African origin. Albeit the Western Carpathians belong to Neo-Europa, their pre-Mesozoic basement rocks represent distinctive analogues of the basement known in the Stille's Meso- and Paleo-Europa. The poly-orogenetic history of the Carpathians basement is characterised by juxtaposition of various terranes and/or blocks that in most cases originated at the Gondwana margin due to multistage tectonic evolution with large-scale nappe and strike-slip tectonics, resulted in the European Variscan collisional orogeny. The pre-Alpine granite-bearing crystalline basement crops out mainly in the Central Western Carpathians (CWC), a heart of the Western Carpathians, consisting of three principal crustal-scale superunits from north to south – the Tatric, Veporic and Gemeric. The Variscan igneous activity in the CWC began by the Late Devonian subduction-related gabbro-dioritic mafic suite having ages between 385 and 370 Ma. Later (365 ~ 350 Ma ago) this mafic suite was followed by the Late Devonian to Early Carboniferous (Early Mississippian) calc-alkaline I-type and/or I/S hybrid tonalites and granodiorites representing dominant granitic suite within CWC that typically occur in Core Mountains of the Tatric Unit and within the Veporic composite batholith. Generally, they are rather metaluminous to subaluminous (ASI = 0.8 ~ 1.2), dominated by biotite tonalite to granodiorite, whereas muscovite-biotite granodiorite to granite are less frequent. The accessory mineral association magnetite, apatite, allanite-(Ce), ± titanite, and locally preserved hornblende along with limited occurrence of mafic microgranular enclaves (MME), are characteristic of this group. However, hybrid I/S granodiorites and granites may also contain monazite-(Ce), ilmenite, ±sillimanite. Lower SiO_2 concentrations 60 ~ 70 wt. %, coincide with higher trace elements Zr, Ba, Sr (up to 380, 1350 and 800 ppm), higher LREE and Fe group element contents. REE patterns are typically steep, with higher LREE and without Eu anomaly. These granitic rocks are clearly richer in CaO, TiO_2 and P_2O_5 than subsequent granites, with ratio $K_2O/Na_2O = 0.5 \sim 0.9$. The initial Sr = 0.704 ~ 0.709; $\varepsilon Nd_{(i)} = -2.8$ to +2.2 clearly indicate interaction with a basic or intermediate (dioritic) lower crustal melt, what is confirmed by their zircon $\varepsilon Hf_{(i)} = -0.3$ to +7.6 as well. The $^{206}Pb/^{204}Pb = 17.99 \sim 18.85$, and $^{207}Pb/^{204}Pb =$

15.53 ~ 15.70 suggest heterogeneous continental crustal source with addition of the recycled subcontinental lithospheric mantle. The stable isotopic ratios with $\delta^{18}O$ = 7.8 to 9.9‰; $\delta^{34}S$ = –2.9 to +2.3‰ and $\delta^{7}Li$ = –1.2 to +0.5 ‰ support melting of a more basic lower crustal protolith. Magmatic intrusion ages of this I-type and/or I/S hybrid granitic group vary between 365 ~ 350 Ma (see our published papers). The Middle Mississippian (Visean) peraluminous S-type granites and subaluminous hybridized S/I-type granodiorites alike previous groups are common in the Core Mountains of Tatric Unit and the Veporic composite batholith, where they made typical intrusion in intrusion (intruding former subduction related ones). They are subaluminous to peraluminous (ASI = 1.0 ~ 1.5), dominated by two-mica granodiorites and granites while biotite granodiorites to tonalites are less common. The accessory mineral association monazite-(Ce) + ilmenite, apatite, ±garnet, ±sillimanite, ±rutile, ±columbite, and the presence of metamorphic xenoliths are typical. Geochemically, Ba, Sr and Rb contents range widely (up to 1600, 600 and 200 ppm, respectively) with Rb/Sr = 0.2 ~ 0.8 (rarely ≤1.8); SiO_2 = 65 ~ 77 wt. % and K_2O/Na_2O = 0.7 ~ 1.4. The contents of CaO, TiO_2 and P_2O_5 are generally low (≤2.5; ≤0.7 and ≤0.3 wt. %). The REE contents are moderate, with more fractionated patterns and a negative Eu anomaly. Initial Sr ratios = 0.706 ~ 0.714; $\varepsilon Nd_{(i)}$ = –7.7 to –1.3; $\varepsilon Hf_{(i)}$ = –7.7 to +2.5; the $^{206}Pb/^{204}Pb$ = 18.39 ~ 19.28 and $^{207}Pb/^{204}Pb$ = 15.59 ~ 15.74, and the stable isotope values $\delta^{18}O$ = 8.8 to 11.3‰; $\delta^{34}S$ = –0.9 to +5.7 ‰, and $\delta^{7}Li$ = –3.2 to +7.0 ‰ indicating a substantial crustal recycling with a minor lower crustal metabasic addition to their protolith. Unpublished SHRIMP zircon and CHIME monazite ages of this S-type and/or hybridized S/I granitic suite range between 343 ~ 330 Ma (our recent unpublished data). Geochemical characteristics of these two principal granitic rocks suites appear partly similar, and because of mainly composite and/or zoned character of the Variscan Western Carpathians granitic bodies with mutual and/or not sharp boundaries between them, there is often a problem to distinguish these suites in the field at the first glance. The successive changes in composition and age of the Variscan Western Carpathians granitic (VWCG) rocks indicate their evolution during several stages of convergent orogeny mainly at an active the Andean-type arc, and the Himalayan continental collisional processes. The VWCG generally intruded variegated the Lower Paleozoic crystalline basement consisting of two principal levels (etages). The lower etage (Cambrian to Silurian in age) is composed by a leptino-ampibolitic complex (LAC) with remnants of retrogressed eclogites, sheared Cambrian-Ordovician felsic magmatites – now orthogneisses, and these metaigneous rocks are intercalated with metamorphosed psammites/pelites with rare carbonatic lenses. The metamorphic conditions of this complex show commonly 650 – 800 MPa and 600 – 780°C, sometimes with characteristic widespread migmatization/granitization (whereas P–T reached up to 1.2 – 2.5 GPa and 700 – 750°C in HP eclogites). The upper etage is formed by typical Upper Silurian – Devonian volcano-sedimentary sequences composed by metagreywackes, phyllites, metabasites (epidote-actinolitic amphibolites), black shales, lenses of calk-silicates, Fe and Pb-Zn Lahn-Dill mineralization, and scarce apatite-rich rocks. Their low-grade metamorphism reached a green schist facies only (below 350 MPa and 650 °C), and weak intrusive migmatitic zones are observed only. Keeping in mind the traditional analogy between the Austro-Alpine and the CWC superunits, one can see the CWC crystalline basement and/or the VWCG origin in subduction of the Paleo-Tethys Ocean beneath the Galatian volcanic arc. However, there is a great similarity to evolution in the Rheic Ocean or the Rheno-Hercynian zone, and/or source connections from the Avalonia and the Hanseatic terranes, what confirms our preliminary detrital zircons study from the CWC crystalline basement metapsammites. Seeing that, available data indicate possible scenario with the double-sided subduction beneath Galatia fragments, a major intracontinental shear zone could explain this situation in the CWC pre-Alpine basement.

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Uranium mineralization near Brezno: geological position and mineralogy (Central Slovakia, Veporic Superunit)

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Occurrence of uranium mineralization near Brezno is located on the eastern slopes of Skalka Mt. north of the Brezno district town (Central Slovakia). Studied mineralization is situated in the Mesozoic formations of the Veľký Bok Unit (Veporic Superunit). Uranium mineralization is bound to mylonitized, partially silicified, Lower Triassic quartzite of the Lúžňa Formation. Occurrence is located near to overthrust fault when Lower Triassic quartzites are overthrusted on Middle Triassic dolomites. Uranium Mineralization was explorated in this area in the 50's of 20th century and verified by short exploration adit and prospection trenches. Primary uranium minerals are total supergene destructed (not preserved). From primary (non uranium) minerals there were identified pyrite and rutile. Accessory minerals of mineralized rocks are chalcopyrite, zircon, apatite and tourmaline. Supergene zone is represented mostly by goethite and uranyl phosphates sabugalite, autunite and metatorbernite. Uranium is distributed within host rocks irregulary or is bound to cracks and small cavities which are filled by uranium phosphates.

Most widespread mineral of the supergene zone is goethite which form filling of fractures and cavities in host rocks. Goethite often forms pseudomorphoses after cubes and pentagonal dodecahedron pyrite crystals. WDS analysis show that goethite contain up to 3.27 wt % of uranium. From the uranium minerals, sabugalite is the most widespread. It form clusters of light yelow tabular crystals, occurs in most frequently in assotiation with less extended autunite and occasionally with metatorbernite. In studied locality was identified unusual chemical transition between sabugalite and autunite („transitional sabugalite"). Chemical composition of sabugalite and transitional sabugalite differs in Al content: 2.68 wt. % for sabugalite and 1.56 wt. % for transitional sabugalite. Transitional sabugalite is charcterised also by increased Ca content (up to 2.8 wt %).

Metatorbernite (formed by spontaneous dehydration of the torbernite), are after sabugalite most widesprad uranium minerals in the studied location. Torbernite forms dark green, well formed dipyramidal crystals (combination of dipyramidal and basal faces) occur in small fractures and cavities, or light green, fine-grained crystals coatings. Lighter green colour crystals of metatorbernite show an unusual light green luminiscence. Autunite si least widespread uranium mineral (usually in close genetic assotiation with sabugalite and transitional sabugalite) in mineralized rocks, where form yelow table-like crystals (up to 3 mm), and rarely form clusters of these crystals.

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Lithostratigraphy and geological evolution of the Kučelach tectonic outlier (Veporské vrchy Mts., Slovakia)

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The study area is located approximately nine kilometres northwest of Tisovec town in the Veporské vrchy Mts. From the regional-geological point of view, the Kučelach tectonic outlier belongs to the Kráľová hoľa zone of the Veporic belt and is formed by several Eo-Alpine tectonic units. The lowermost, Vepor tectonic unit is represented by Upper Devonian to Lower Carboniferous metagranitoid rocks forming the Variscan crystalline basement. The fundament is covered by Permian to Lower Triassic siliciclastic deposits, which gradually pass to Middle to Upper Triassic carbonate sedimentation with Middle Carnian fluvial event and belong to the Foederata cover sequence. Younger deposits than Upper Triassic are unknown so far. The Vepor Unit is overridden by the Gemer Unit, which is characterised by metamorphosed volcanosedimentary formations, which is the new structural element in the Kučelach ourlier. Based on the litostratigraphic criteria, the sedimentary succession is well comparable with the Furmanec or Ochtinná Subunit. Both, the Vepor thick-skinned unit and Furmanec Subunit overcame greenschists to amphibolite facies Alpine metamorphosis and are covered by unmetamorphosed thin-skinned Vernár-Muráň nappe system related to the structurally highest unmetamorphosed Silica Unit. The sole of the Muráň nappe is formed by the Upper Permian to Lower Triassic sandstones and shales with small bodies of rhyolites passing upwards to marlstones and limestones. The Middle to Upper Triassic rocks represent the substantial part of the filling of the Muráň nappe in the area of Kučelach tectonic outlier. The Anisian carbonate platform was partly destroyed by a marked Pelsonian rifting event, which led to the formation of intra-shelf basins filled with hemipelagic nodular limestones and resedimented carbonates. These rocks were replaced by the Wetterstein carbonate platform in Late Ladinian to Cordevolian and the younger sediments than Cordevolian are missing due to erosion. The Upper Eocene to Oligocene sediments rest in overstepping position over the Eo-Alpine nappes. The rocks form the Cenozoic post-nappe cover in the study area and belong to the Horehronie Palaeogene sequence, which is considered to be a part of the Central Carpathian Palaeogene Basin. This geological structure is intruded by subvolcanic andesite bodies of the Tisovec Intrusive Complex.

Geotectonic position of the Lhasa Block during Early Jurassic time from paleobiogeographical perspective

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Geotectonic, paleogeographical position of the Lhasa Block during Mesozoic times is still a matter of discussion. Its Late Paleozoic (Carboniferous-Permian) and Triassic south Pangean (peri-Gondwanan) affinities on the southern margin of the Paleotethys are indicated both by paleomagnetic and facies studies. Separation of the Cimmerian continent [Iran (Alborz)-Qiangtang-Malaysia-Sibumasu] from this part of Pangea during the latest Carboniferous–earliest Permian times by rifting and drifting event originated Neotethyan Ocean and therefore, the Lhasa Block belonged to the southern margin of this new ocean. Northwards migration of the Cimmerian continent took place during Permian-Triassic times causing wide opening of the Neotethys and closing of the Paleotethys Ocean. The Late Triassic Indosinian orogeny has been one of the most spectacular geotectonic events reflecting collision of this continent (mainly Sibumasu part) with the Indochina Block. The new break-up of southern Pangea and especially separation of the Lhasa Block from Gondwana is enigmatic but most probably took place during the earliest Jurassic times and that is why this terrane started a quick shift northward.

On the other hand, recovery of marine fauna after Triassic/Jurassic mass extinction event was mainly marked by *Lithiotis*-type bivalve buildups distribution (e.g., *Lithiotis*, *Cochlearites*, *Lithioperna* and *Mytiloperna*). Huge, up to 40-50 cm long bivalves, which dominated within this so-called *Lithiotis*-facies, are the most significant representative of the buildup-makers of shallow marine/lagoonal bivalve mounds ("reefs"/buildups) in numerous places of Tethyan-Panthalassa margins during Pliensbachian-Early Toarcian times. This T/J mass extinction ranges fourth in the Big Five in terms of taxonomic loss because more than 50% of the marine genera and about 80% of the species went extinct. Reef communities were especially affected and that is why *Lithiotis*-bearing deposits documented the biggest reef-type organic buildups after this biological crisis. The world-wide distribution of these bivalves indicates very rapid expansion of such type of bivalves along southern margin of the Neotethys – from northern Africa (Morocco) and southern Europe (Spain, Italy, Croatia, Slovenia, Albania and Greece), through westernmost Asia/Arabia (eastern Turkey, Iran, Iraq, Kuwait, Oman) to central Asia (India, Nepal, China), including so-called Kioto Carbonate Platform (carbonate sedimentation predominated along the southern Neotethyan margin). Their sedimentological and paleoecological regimes were studied according to paleogeographical reconstruction of facies around the Pangea at that time, and their Early Jurassic migration routes were connected both with break-up of Pangea and oceanic circulation, which facilitated high speed of distribution of larvas of such oyster-like bivalves. Therefore, the Himalayan and Tibetan (Nyalam area) occurrences of *Lithiotis*-type bivalves could help to reconstruct the Early Jurassic position of the Lhasa Block.

When the supercontinent Pangea was formed during the Carboniferous time as the result of the Hercynian orogeny, the separation of Laurasia and Gondwana, which was initiated by the Triassic break-up of Pangaea, continued during the Early-Middle Jurassic times. The Early Triassic continental rifting was magnified at the Triassic/Jurassic boundary and the Atlantic Ocean originated as a consequence of this break-up. In effect, the origin of the narrow sea strait, so-called Hispanic Corridor, took place between these two continents and connection of the Panthalassa Ocean (Proto-Pacific) and western (Alpine) Tethys gradually started in Early Jurassic (the most probably in Sinemurian-Pliensbachian times). Therefore, the widespread distribution of numerous fossil invertebrate groups took place during these times. It is open question, which migration route has been used by *Lithiotis*-facies bivalves to their whole world dispersion, trough Hispanic Corridor or by Panthalassa Ocean? And especially, the buildups in Middle Asia (e.g., Iran – Alborz and Zagros regions) and Himalayan region (with south Tibetan locations) are important, because occupy midway of such path and was connected with geotectonic migration of several terranes during Early-Middle Jurassic times, most probably including the Lhasa Block as well.

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Detailed study of two selected quartzo-feldspathic rock bodies in the central part of Erzgebirge Mountains

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The central part of the Erzgebirge Mountains is composed of Proterozoic and Early Paleozoic metagranitoids and metasedimentary rocks. This area is currently understood as a stack of various UHP-HP and HT tectonometamorphic units resulting from the Variscan continental subduction-collision process.

The studied area reflects the sequence of parautochthonous and overlaing allochthonous units. The Katerina-Reitzenhain granite-gneiss amphibolite unit / parautochthonous unit at the bottom is overlain by several allochthonous units consisting of high-grade metasedimentary rocks, orthogneiss and subordinate metabasite that locally preserve HP or even UHP conditions. From the structural bottom to the top: i) HP unit 1 / Gneiss Eclogite Unit II; ii) HP unit 2 / Gneiss Eclogite Unit I and iii) HP unit 3 / Micaschist Eclogite Unit.

The problem of orthogneiss bodies in the central part of the Erzgebirge Mountains is their basic mineral assemblage. The lack of preserved garnets all over the studied area including both, parautochthonous and allochthonous units, does not allow to estimate precise PT conditions. Thus, our previous study in this area was based mainly on the microstructural analysis and allowed us to propose a model of consecutive underplating of accretionary wedge by deeply subducted material that is successively exhumed from the subduction channel.

This research is focused on two individual quartzo-feldspathic rock bodies which are unique for their preserved mineral assemblages, which notably include garnets. These rock bodies are located in the allochthonous units, specifically in Gneiss Eclogite Unit II (GEU II) and Gneiss Eclogite Unit I (GEU I). The lithology of both outcrops consists mainly of orthogneiss, with interlayered granofels, which have a similar mineral assemblage, including garnets, but different texture and thus microstructure.

The outcrop located in GEU II is unique because we were able to study the differences of augen orthogneiss through banded orthogneiss / mylonite to granofels in the vertical scale of approximately 1m. In the Gneiss Eclogite Unit I the outcrop is dominated by orthogneiss rarely interlayered by granofels.

The geochemical analysis of studied samples supported by presence of coesite in the orthogneiss of GEU I, suggesting UHP conditions. Our study thus highlights the importance of these two individual rock bodies in unravelling the complex evolution of the central part of Erzgebirge Mountains.

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Modes and geometry of the lower crust detachment folding for various heat-based rheological gradients - insights from physical modelling

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The concept of the detachment folding was developed between the 60's and 80's and generally describes displacement and buckling deformation of a competent layer above a weak, usually low viscosity, horizon during tectonic shortening. From this definition and based on the Biot-Ramberg theory it is clear that geometrical parameters of such folds depend on contrasting rheology in both layers or on a rheological gradient in a complex multilayer. These systems were originally studied in the relationship to the thin-skinned deformation and salt tectonics, and recently in association with large-scale lithosphere deformation. Here, the rapidly heated lower crust is partially melted and a thin melt layer at the MOHO depth serves as a detachment horizon during collision and shortening.

Our experimental work contributes to understanding of the geometrical, kinematic and dynamic behaviour of such types of the detachment folds as this deformation process strongly depends on a thermally dependent rheological gradient and nonlinear shortening velocity. The natural prototypes for our models are for example Chandmann or Bugat metamorphic domes in Central Asia (CAOB). Our aim is to parametrize the style of such crustal-scale detachment folds depending on the rheological properties of the layered crust and the thermal gradient.

For this purpose, we developed an apparatus for thermal analogue models capable of producing thermal gradients and programmable shortening. Paraffin wax is used as the analogue for partially molten lower crust. It has a convenient melting potential and serves well for representing the middle-lower crust. As an overlying upper crust, we chose granular materials - a combination of a low-density glass beads and silica sand, respectively. To keep the models dynamically scaled, we rescaled the relationship for progressively decelerated plate convergence and orogeny and applied it for our model - as one of the variable parameters together with the rate of basal heating.

With increasing of both, basal heating and shortening rate, the folds finite geometry converges to a system of pseudo-symmetric folds, cored by various amounts of the melt in a dependence on their position in the fold sequence. Dynamics of the folding also depends on position and generally has four evolutionary steps including initial perturbation, amplification with the melt inflow, locking and vertical extrusion.

With decreasing degree of basal heating, the total melt amount is lower, deformation is more localized and converges to a brittle-ductile coupling. Typical products are rather thrust systems on a local scale or pop-up structures on a large scale. Melt is localized in form of small fingers underneath the pop-up structures.

In higher degree of heating, the melt is distributed continuously along the axial planes of folds. Analysis of the layer interfaces curvature and tortuosity of the material particles in these higher heating experiments (based on resultant displacements calculated by the PIV method) also revealed asymmetrical evolution of the P-T-t paths for associated limbs of pseudo-symmetrical folds.

Mass balance of Y+REE during atoll garnet formation in eclogite facies rocks

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Garnet incorporates high concentrations of Y and rare earth elements (REEs) and their partition during garnet growth is governed by Rayleigh fractionation. The mass balance of Y+REEs during decomposition-dissolution and regrowth of garnet become an important tool for a reconstruction of multistage and atoll garnet formation. For this study, high pressure metabasites with atoll garnets from the central part of the Krušné hory Mts. (Saxothuringian Zone, Bohemian Massif) were used. Peak-pressure phases are represented by garnet, omphacite, quartz, amphibole, rutile and talc. Relicts of early developed zoisite were also observed. Among common retrograde minerals belongs amphiboles, ilmenite, plagioclase and chlorite.

Based on compositional profiles and maps of main and trace elements two generations of garnet were distinguished. The older garnet (I) is represented by Ca rich interior parts of grains and younger garnet (II) by abundant Mg content on the rims or replacing interior garnet I during atoll formation. Prograde development of garnet I is marked by decreasing Ca and Mn and increasing Mg content from core toward the rims. Garnet II on the rims shows often higher amounts of Mn than the rim-part of interior garnet I. Because garnet is the main phase carrier of Mn, its high concentration in garnet II is explained by Mn releasing during dissolution of garnet I and its incorporation into garnet II.

To quantify dissolution and reprecipitation of garnet during atoll garnet formation, the Y+REEs concentrations in garnet were analysed. Especially heavy REEs (HREEs) and Y, which has good compatibility in garnet and low diffusion coefficient. The interior garnet I shows clear zoning with a decrease of Y+HREEs from core toward the rim. At the interface with rim garnet II, the Y+REEs contents increase, which is related to the breakdown of core garnet I and other accessory Y+REEs rich phases, such as zoisite or lawsonite. The rim garnet II shows mostly lower concentrations of Y+HREEs, but higher light REEs (LREEs) contents comparing to the interior garnet I.

Two approaches were considered for the mass balance of Mn+Y+REEs between garnet I and II. The first uses calculation of percentage volumes of Mn+Y+REEs in small segments across compositional profile of large garnet grain (segments shown in Fig. 1a). The results of this approach are shown in Fig. 1b. In the second case, mass-balance calculation was applied to small garnets measured in a section of 3×1.7 mm, calculating with mean element contents of garnet I and II. These contents were multiplied by the garnet modes of relict garnets I, its dissolved parts and garnet II obtained by image analysis (cut-out of images on Fig. 1c, d) and recalculated on 100 % (results presented in Fig. 1e). The two methods are compared in order to discuss the accuracy of the results for the final mass balance quantification.

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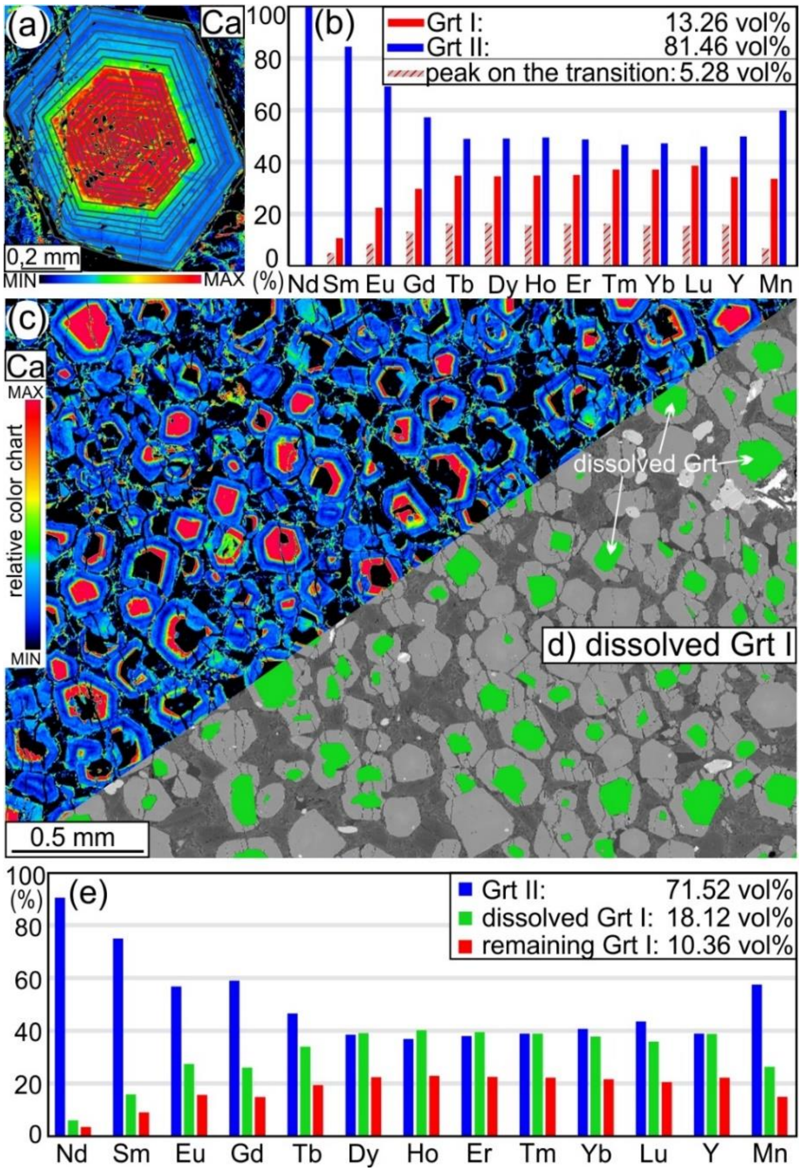

Figure 1: Graphical presentation of mass balance of Y+REEs between interior garnet I and rim garnet II; **a)** Ca map of garnet with illustrated segments measured for mass balance calculation; **b)** summarized contents of Mn+Y+REEs relating to its percentage volumes of segments in garnet I, II and transition zone; **c)** measured section with whole and atoll garnets visualized by compositional map of Ca; **d)** BSE image of the section with illustrated dissolved parts of garnet I – coloured green; **e)** contents of Mn+Y+REEs relating to the recalculated modes of dissolved garnet I, remaining garnet I and stable garnet II.

Feldspars as an indicator of mixing in the Variscan Krivánska Fatra granites (Šútovo gorge)

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The Malá Fatra Variscan crystalline segment formed peraluminous hypersolvus tonalite and granodiorite. Compositional feature of feldspars in the eastern Kriváň part of Malá Fatra evidences that granite massif was originated in mixing regime. The samples of transitional tonalite/granodiorite rocks, granodiorite and monzogranite have been investigated from the Šútovo gorge.

Three types of plagioclase have been determined in granodiorite. Plagioclase I (X_{An} = 0.24 – 0.32, locally up to 0.36) forms zonal idiomorphic grains making up a cumulate-like texture and reflect progressive magmatic crystallisation. Plagioclase II (X_{An}=0.22 – 0.17) is principal mineral in monzogranite but also form rims on plagioclase I as a product of post magmatic low temperature overprint. In plagioclase core was identified relic, plagioclase III of andesine-labradorite composition (X_{An}=0.41-0.50) which breaks down to albite+sericite/ muscovite+epidote association. Such association was distinctly identified in almost all grains of plagioclase from different samples showing an abundance of primary very basic “hot” plagioclase within investigated terrain. Plagioclase in tonalite is strongly sericitised and sassuritised but well preserved grains with An in cores up to 33 mol. % (in average ca. 30 mol. %) but in altered plagioclase average is 26 An mol. %. Impregnation of numerous sericite and hematite particles caused visible red colouring of plagioclases. Moreover, on mixing process points to an existence of two types of K-feldspar. K-feldspar I is primary magmatic, in granodiorite forms individual hypidiomorphic grains as well as coarse-grained phenocrysts (up to 1.5 cm) in monzogranite. Internal oscillatory progressive zonal structure is due to variation of BaO content (from 1.0 to 2.6 wt.%) showing bell shape magmatic trend. Content Na_2O even after exsolution to perthite is still up to 1 wt.%. K-feldspar II originated on the rimes of K-feldspar I or is present in plagioclase interstitions and contains low BaO content (<1.0 wt. %). Important is a finding of the relic sodium rich K-feldspar (Na_2O and BaO are up to 1.64 wt. % and 2.5 wt.%, respectively) what indicates mixing in the crystal cores. Two different trends in K-feldspar, growing in stages could be explained by changes of geodynamic regime, oscillating of K, Na, Ba, Si, H_2O in residual melt and intensive melt mixing.

The P-T-X conditions for origin of investigated feldspars from granodiorite were calculated using Perplex_X thermodynamic software (Connolly 200: version 6.9.0). The solidus curve was estimated in 700 °C at accepted pressures 500-600 MPa. Plagioclase I with An content 26-36 mol. % crystallised above the solidus curve in temperature range of 700-750 °C that is in a good agreement to temperatures of 735-756 °C obtained from magmatic Fe-Ti oxides. Below this temperature there is a stable plagioclase with An component of 24-26 mol.%, which can be stable down to a temperature of 520-550°C and below this temperature it breaks down to epidote+albite+muscovite assemblage. The K-feldspar has been significantly re-equilibried during late magmatic alteration. The highest temperatures calculated by feldspar geothermometer vary from 550 to 580°C (calculated at 550 MPa). Multistage formation of plagioclases in both tonalite and in a relics in granodiorite indicate hot magmatic chambers and intensive mixing like in the MASH zone.

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Effect of deformation localization on the anisotropy of magnetic susceptibility

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Anisotropy of magnetic susceptibility (AMS) is very often applied as a tool to infer structural analysis of deformation and flow in rocks, particularly, with low anisotropy. AMS integrates the magnetic signature of crystallographic and shape preferred orientation of all mineral grains present in the rock microstructure. However, those preferred orientations result from multiple processes affecting the rock during its evolution, therefore the desirable AMS-strain relationship is not straightforward. Consequently, the microstructure of a deformed rock is often a complex combination of distinct microstructural features of diverse orientations and strengths. Therefore, it is not only important to evaluate the contributions of the main susceptibility carriers to the anisotropy, it is also important to identify the processes responsible for AMS development and their eventual superposition.

We derived the relationship between AMS and strain in a marble shear zone by combining rock magnetic studies, detailed microstructural analysis and CPO-based numerical modelling of the AMS. AMS ellipsoids are characterised by k1 orientation as being at a high angle to the primary fabric and experience gradual rotation towards the SZ plane with increasing strain. The k1 orientation is consistent with the calcite c-axes preferred orientation, which is considered to represent an "inverse" AMS fabric, because the "normal" AMS fabric should show k3 parallel to c-axes. Moreover, the AMS shows an angular deviation from the local macroscopic fabric observed in the shear zone. The microstructural evolution related to the shear zone development is characterised by dynamic recrystallization of a primary coarse-grained calcite microstructure. The increasing strain is accommodated by increasing the amount of recrystallized matrix at the porphyroclasts expense. To interpret inverse magnetic fabric and observed strain-AMS relationship we have implemented numerical modelling. Models are constructed based on microstructure, CPO, modal and chemical composition of constituting minerals.

The localization of deformation at P-T conditions of dislocation creep leads to the contemporaneous evolution of two microstructural subfabrics in the marble. The combination of their respective magnetic signals results in distinct orientation of total AMS and local macroscopic fabric. This means that neither strain magnitude nor its orientation derived from macroscopic fabric orientation would correspond to estimates deduced from AMS. The combination of magnetic signal of distinct subfabrics also influences the shape and strength of magnetic anisotropy.

We show that due to localization of deformation, AMS is indirectly dependent on the magnitude and character of deformation. In order to decipher the AMS-strain relationship, AMS studies should be accompanied by microstructural analyses combined with numerical modelling of magnetic fabric.

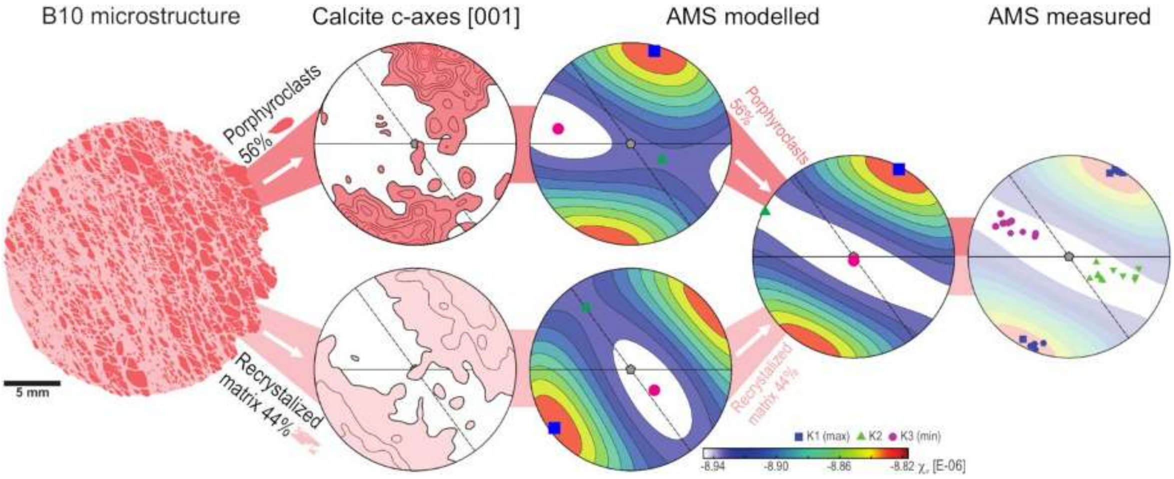

Figure 1: Analysis of deformation localization influence on AMS. From left to right: digitized microstructure of sample B10, calcite c-axes preferred orientation of porphyroclasts and recrystallized matrix in sample B10, modelled AMS signal of porphyroclasts and recrystallized matrix, combined modelled AMS signal from sample B10 based on the actual proportion of porphyroclasts (56%) and matrix (44%) and comparison with measured AMS in sample B10.

Internal architecture of the Saxothuringian Unit – a possible result of two orthogonal deformation events

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Recent petrological, geochronological and microstructural studies provide new constraints on formation and tectonic evolution of the Saxothuringian Unit. It is generally accepted that subduction of the Saxothuringian Ocean and the leading edge of the Saxothuringian continental crust resulted in formation of large-scale continental wedge, which occupies substantial part of the Saxothuringian Unit. On the other hand, its internal architecture, timing and direction of convergence are still subject of debate. In this contribution, we demonstrate that two major tectonic events are responsible for complex structure of the Saxothuringian Unit.

During the Late Devonian – Early Carboniferous the eastward subduction of the Saxothuringian Ocean formed continental wedge characterized by exhumation of UHP rocks in its rear part and blueschists and high-pressure phyllites in its frontal part. Detailed petrological and microstructural studies revealed continuous change from a relatively cold geothermal gradient related to prograde evolution followed by rapid heating contemporaneous with exhumation of hot UHP rocks and bulk vertical shortening interpreted as ductile-thinning of the wedge. Based on the existing and newly obtained geochronological data the latter tectono-metamorphic event is bracketed by an age of ~340 Ma.

The second major tectonic event resulted from a regional change in convergence direction, documented at several places along the Variscan Belt. In the Saxothuringian Unit, this change is associated with southward indentation of the former wedge by a promontory of the northerly continental segment with an affinity to Lausitz block. In the present day structural arrangement, this segment is represented by several tectonic windows referred to as the so-called “para-autochtonous unit” of the Erzgebirge. The second deformation event is characterized by strong transposition and folding of the earlier fabrics and development of steep E-W trending foliations along the southern front of the indentor. Major part of the former crustal wedge was thrusted over the indentor and forms important part of the so-called “alochtonous unit” of the Erzgebirge. Finally, the whole studied region is heterogeneously affected by late upright folding responsible for formation of characteristic antiformal and synformal structures across the Saxothuringian domain.

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Origin of magnetic fabrics in turbidites of the Central Carpathian Palaeogene Basin: insights from AMS and AARM study

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The anisotropy of magnetic susceptibility (AMS) is a valid and rapid petrofabric technique used in the study of preferred orientation of different origin in rocks. It utilizes the parallelism between the orientation of magnetic susceptibility ellipsoid with the orientation of sedimentary, magmatic or tectonic fabrics of rocks. Here we present analysis of the AMS and anisotropy of anhysteretic remanent magnetization (AARM) of different depositional facies from the Late Eocene to Oligocene mostly turbiditic succession of the Central Carpathian Palaeogene Basin (CCPB). Comparison of magnetic fabrics with orientation of sedimentary (flute casts, slump folds) and deformation features (joints, faults and folds) was performed. We sampled 319 independently oriented cores at 20 sites in the Liptov and Poprad depressions, Orava region and Spišská Magura Mts. In northern Slovakia. For comparison we used the AMS and AARM data from 17 sites from the Podhale region in southern Poland and from the Levoča Mts. and Šariš Uplands in Eastern Slovakia. Observed magnetic susceptibilities ranged in 66-365 10^{-6} SI, implying that the AMS signal was mainly governed by paramagnetic minerals. The AMS fabric was generally oblate, but neutral or slightly prolate fabric was observed as well. Isothermal remanent magnetization acquisition curves and subsequent thermal demagnetization of the three orthogonal components revealed the presence of a magnetically soft mineral in both pelitic and psammitic rocks. The minimum susceptibility axes K3 were, in almost all cases, perpendicular or gently inclined to the beddings. In the Ta, Tb and Tc intervals of the Bouma sequence, the maximum susceptibility axes K1 were parallel to flow directions inferred from the nearest flute casts. In sandstones with a convolute lamination or with hydroplastic deformation features, the K1 axes were oriented parallel to the syn-sedimentary fold axes and K3 axes created girdles perpendicular to K1. Mudstones yielded K3 axes situated near the bedding poles and well grouped K1 axes parallel to the measured flow directions. The AARM, displaying solely ferromagnetic fabric, was oriented generally differently to the AMS. The AARM type 1 represents steep magnetic foliations oriented NNW-SSE or to NE-SW. In the AARM type 2 magnetic foliations remained parallel to the bedding while magnetic lineations gently plunge to NW/NNW. The AARM type 3 coincides with the AMS fabric. The AARM type 1 magnetic foliations show a good coincidence with the prominent NW/NNW-SE/SSE and NE-SW joint system, well visible mainly in the more competent sandstone beds. Previous studies proved that the joints, often filled with calcite and quartz, formed during burial and incipient inversion of the CCPB during the Early to Middle Miocene. Magnetic and microscopic analyses indicate

that the AARM fabrics are connected to magnetite associated with subordinate ferrimagnetic iron sulphides. Both minerals occur in a sub-microscopic size and formed most likely during late diagenesis through the alteration of pyrite, possibly accompanied by burial clay transformation processes. Conclusively, the present study documents that the AMS represents the sedimentary fabric, controlled mostly by the orientation of paramagnetic minerals, originated during the deposition and subsequent syn-sedimentary deformation of poorly lithified sediment. The AARM sub-fabric reflects the orientation of authigenic ferrimagnetic minerals. The growth of the authigenic ferrimagnetic minerals was conditioned by combined effects of the sedimentary petrofabric, lithology and stress conditions during the inversion of the basin in the Early to Middle Miocene.

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Subduction and exhumation of continental crust in the Variscan Bohemian Massif – a numerical modelling study

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In the Variscan Bohemian Massif, numerous outcrops of highly metamorphosed felsic rocks witness deep subduction and exhumation of continental crust. These outcrops are characteristic for the Moldanubian domain, which has been interpreted as a denuded root of the Variscan orogen. More specifically, in this domain, an assamblage of (U)HP felsic granulites and orthogneiss, eclogites, peridotites, and ultra-potassic plutons alternates with less metamorphosed mid-crustal rocks. Interestingly, the age patterns and chemistry of inherited zircons as well as the bulk rock chemistry show that the (U)HP felsic rocks originate from the Saxothuringian domain which was a part of the lower plate during the Variscan collision. For some rocks that implies a horizontal displacement of more than 300 km from their original position. To explain these observations, a tectonic scenario has been proposed that includes subduction of a continental tip, detachment of continental crust from the subducting lithosphere, flow of the crustal material beneath the upper plate and its diapiric exhumation into the middle crust. We test the feasibility of this scenario using numerical models.

We use two-dimensional thermal-mechanical models that take into account non-linear visco-plastic rheology, percolation of fluids, melting, melt extraction and melt emplacement. Our models simulate oceanic and continental subduction and they are designed to study formation of the (U)HP rocks and their displacement far from the site of subduction. Our main focus is the relationship between selected model parameters and kinematic and pressure-temperature evolution of the subducted continental crust.

In our models, the continental rocks are first subducted along with the lower plate. During this stage they attain maximum pressures of ~30–50 kbar. The maximum depth (and pressure) increases with the prescribed strength of the rocks and with the velocity of subduction. In any case, thermal weakening due to deep subduction finally causes detachment of the continental crust from the subducting plate. The detached crust rises due to its compositional buoyancy, but its motion is restricted by the strong lithosphere of the upper plate. As a result, the subducted crust spreads beneath the upper plate at a depth that corresponds to its thermal thickness (pressure of ~20–25 kbar). During this sub-lithospheric flow, the crustal material gradually warms up due to the contact with the surrounding mantle. The maximum temperature can reach 800–1000 °C and depends of duration of this flow (~5–20 Myr).

At these ultra-high temperatures, the crustal material melts partially. During the flow the crustal and mantle material can mix, water can percolate from the subducted rocks into the mantle and induce its hydration and melting. Such melting of the continental and mantle material can explain the presence of ultra-potassic plutons accompanying the (U)HP complexes in the Moldanubian domain.

Finally, the subducted material is exhumed in the form of a diapir through the lithosphere. This exhumation is very quick and results into nearly isothermal decompression. The site and timing of exhumation depends of many factors. The key process that triggers exhumation is the weakening of the lithosphere of the upper plate by melts rising through it. Exhumation therefore occurs earlier in models with lower solidus of the subducted material. In addition to the formation of the trans-lithospheric diapirs, some models show exhumation along the plate interface in the form of a wedge or a channel. In that case, the exhumed material records heterogeneous peak conditions because it samples different levels of the subduction zone. Such evolution can represent formation of the metamorphic complex that is located along the eastern margin of the Saxothuringian domain, i.e. along the contact of the upper and lower plate.

Subduction-collision and exhumation processes in the Arctic Caledonides – petrological proxies from HP rock complexes

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The North Atlantic Caledonides extend from the Appalachians through the British Isles and Ireland, northernmost Germany and Poland towards Scandinavia and Greenland reaching the High Arctic. In the Arctic, the Caledonides form the most prominent Phanerozoic orogenic belt, including the northernmost Scandinavian Caledonides and the entire Greenland and Svalbard Caledonides. Additionally, Caledonian signatures can be traced on Franz Josef Land and within the Pearya Terrane of northern Ellesmere Island. Several occurrences of high-pressure (HP) to ultrahigh-pressure (UHP) rocks have been identified in the Arctic Caledonides. The oldest of them are blueschists and eclogites of the Seve Nappe Complex in the Norrbotten county of Sweden and the Västgötabreen Complex of western Svalbard that were formed during late Cambrian to early Ordovician intraoceanic subduction or as an effect of Baltica(?) outermost margin subduction and subsequent collision with an island arc (or arcs). Interestingly, several lines of evidence suggest that lawsonite and other low temperature HP phases were stable in these rocks which makes them the oldest witnesses of cold subduction at the onset of the Iapetus Ocean closure. Younger, mid to late Ordovician eclogites are known from the Richarddalen Complex of Svalbard and the Tromsø Nappe of continental Norway. The Richarddalen eclogites occur within Neoproterozoic metaigneous basement of either continental or ancient island arc origin. It is not known whether the Richarddalen Complex was formed during a subduction beneath an island arc or a (micro)continental plate. Also, provenance of the Richarddalen Complex remains unknown. Equally enigmatic are the UHP Tromsø Nappe eclogites and associated metasediments, some of them containing diamond, that were traditionally thought to have formed along the Laurentian margin. However, an alternative tectonic scenario in which the Tromsø Nappe is a part of middle to late Ordovician subduction complex, which formeddue to collision with an island arc in relative proximity to Baltica is also plausible. Less enigmatic are early Devonian eclogites occurring within the Baltica crystalline basement cropping out on the Lofoten archipelago that were formed during the main Scandian phase of the Iapetus closure at the onset of the Baltica-Laurentia collision.

Similar tectonic setting is inferred for the formation of broadly coeval HP rocks from Liverpool Land in the southern segment of the East Greenland Caledonides. However, the youngest UHP rocks in the Arctic Caledonian realm are known from Germania Land (including Rabbit Ears Island) of the northern segment of the East Greenland Caledonides. These lithologies were formed during the terminal stage of the Caledonian Orogeny due to substantial thickening of the continental crust.

In this contribution we are going to review all the aforementioned occurrences of HP and UHP rocks in the Arctic Caledonides. We will pay special attention to the newest discoveries from Svalbard and present pressure-temperature-time histories of these rocks and speculate on their local as well as broader, regional tectonic context.

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The 3D model of the sedimentary cover of the Gorzów Block

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The last few years at the Polish Geological Institute - National Research Institute (PGI-NRI) has brought an increased focus on systematic geomodelling aimed at mapping systematically all Polish sedimentary basins in 3D. This 3D mapping campaign has produced its first, pilot model, which is the Lublin Basin. Next in the line – Gorzów Block model – is just finished. We aim to capture basic geological knowledge in an accessible and re-usable format, allowing further research and subsurface use planning. To produce these models, we engage geologists specializing in resolving regional problems, thus preserving and promoting their knowledge.

The 3D model of the sedimentary cover of the Gorzów Block was developed in Petrel software from Schlumberger (license under donation agreement) and Gocad / SKUA from Emerson (formerly Paradigm). An extensive set of geophysical and geological data was used to construct the model: digital versions of over 30 2D and 3D seismic images provided courtesy of PGNiG, borehole geophysics and other data from more than 300 deep boreholes, and numerous archival materials. In the analysis of seismic data, interpretations of seismic horizons made by Geofizyka Toruń and own interpretations prepared mainly for shallow horizons within the Cretaceous, Jurassic and Triassic were used. In the correlation process of boreholes, stratigraphic and lithostratigraphic boundaries were verified. Sedimentation environments were also interpreted in the entire Permian-Mesozoic profile, and lithology groups were identified in Carboniferous.

The basic model is the structural model, which consists of a fault network model and the main stratigraphic surfaces (16) and lithostratigraphic separations (over 40). Within it, parametric models were made - grids storing lithology, deposition environments, porosity, permeability and other parameters.

PGI-NRI carries on development of intuitive viewers of modelled geological structures of sedimentary basins both on desktop and in the web: http://webcad.pgi.gov.pl/geo3d/en/projects. Current functional versions allow the viewing of solid models, cross-sections, horizontal section maps and virtual boreholes.

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Multistage evolution of granitoid magmatism in the Low Tatra Mts., Western Carpathians based on preliminary SHRIMP zircon and U-Th-Pb monazite geochronology records

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Low Tatra Pluton (Tatric Superunit) is exceptional in frame of the other Variscan West-Carpathians granitoid suites due to existence of compositionally variable granitoid subtypes, which genetic relationship are not constrained yet in detail. Here we present preliminary interpretation of multistage evolution of felsic peraluminous magmatism in the Low Tatra Mts. based on SHRIMP zircon and U-Th-Pb monazite datings.

The investigated granitoid types are 1) tonalitic diatexite from migmatite zone located between granitic massif and orthogneisses complex 2) spatially heterogenous Prašiva I/S type granite to granodiorite (allanite-bearing in W part and monazite-bearing in E part) and 3) leucogranite dykes enclosed in Prašiva granitoid (in Dúbrava mining field) in low-grade phyllites (Klinisko).

In diatexite, zircon shows age of 360.4 Ma, while monazite records significantly younger imprint ages of ca. 349 Ma. Zircon ages in allanite-bearing Prašiva type yielded mean age of 351 Ma. In many cases, when cores show age range of 355-350 Ma, rims are significantly younger 340-330 Ma. The bimodality is visible also in monazite ages of mnz-bearing facies, which yielded mean average 354 Ma and two populations 350-360 Ma and 340-330 Ma, respectively. Zircon and monazite ages of leucogranites clustered about 351-349 Ma. Ages <320 Ma, identified in some zircons and monazites in all studied granites, were interpreted as a Permian or Alpine tectonothermal overprint.

The geochronological data record at least three evolutionary stages in ca. 360, 350 and 340 Ma. The oldest, from migmatite zircons and some zircons and monazite from cores in granitoids, signalize peak of HP metamorphism and probably subduction of Paleotethys beneath Galatian superterrane and coincident with time relations in analogous lithologies elsewhere in Western Carpathians. Zircon ages decouple from almost 10 Ma younger monazites are in coincidence with timing of leuogranitic magmatism and may refer to anataxis during early (post)collisional stage. Ages ca. 353 in Prašiva granite advocate late-subduction setting of magmatism, however, large share of younger (345-340) monazites and zircons is equivocal and may be related to collisional thermal overprint or even partial re-melting. The preliminary geochronological framework of Variscan magmatism in the Low Tatra Mts. corresponds to findings in the close Malá Fatra Massif indicating a common magmatic history.

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Joint interpretation of paleomagnetic, structural and AMS results from the Vardar Zone of Serbia

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The Vardar Zone is a highly complicated suture between units of African and European affinities, which also contains remnants of an oceanic domain. This domain was characterized by extensional opening during the Triassic and Jurassic. In the Upper Jurassic, the oceanic lithosphere was obducted, simultaneously over the continental units of African and European origins, respectively. The remnant of the oceanic crust, however, persisted in the Sava Zone till the Late Cretaceous-Eocene continental collision. During the final closing, the flysch sediments of the Sava Zone were trusted over by the sediments of the Eastern Vardar Zone along a generally NNW-SSE trending fault system, which is called Bela Reka Fault in the Belgrade area. The flysch of the Sava Zone, in its turn was trusted over the Western Vardar Zone. During the Oligocene and Lower Miocene there was an intensive igneous activity in the Vardar Zone. The products of this activity are widespread in the Eastern well as in the Western Vardar Zone, while in the Sava Zone they are known from a restricted area.

To date, we carried out paleomagnetic and AMS studies on oriented rock samples which were drilled at 39 plus nine localities /sites from the Western and from the Eastern Vardar zones, respectively. From these zones Upper Cretaceous sediments and Oligocene-Lower Miocene igneous rocks were studied. The Sava Zone is represented by 16 Upper Cretaceous localities, where marls and marly limestones were collected. The structural observations from the Sava and Eastern Vardar zone lend themselves to interpreting them jointly with the paleomagnetic and AMS results. Those from the Western Vardar Zone provide a general frame by defining the main events with the character and the orientation of the strain field.

The paleomagnetic results from both the Western and Eastern Vardar zones point to about 30° post-Oligocene CW rotation. This rotation is indicated by the primary paleomagnetic signals of the igneous rocks and the secondary magnetizations of the sediments, imprinted during the magmatic activity. This rotation must have occurred after the Lower Miocene (youngest igneous rock exhibiting rotation), but the upper age limit is not yet constrained. Nevertheless, this must be taken into account when interpreting the orientations of the pre-Lower Miocene stress fields. This applies also to the Sava Zone, which was at the time of the igneous activity sandwiched between the Western and Eastern Sava zone.

The sediments of the Sava Zone which were intensively folded during an Upper Cretaceous/ Paleogene compression have secondary magnetizations, which are definitely not connected to the Oligocene-Lower Miocene magmatic activity. They are difficult to date, could have been acquired before or after the 30°CW rotation of the Vardar Zone. The distribution of the locality mean paleomagnetic directions seem to suggest moderate vertical axis rotations after the acquisition of the paleomagnetic signals. The AMS fabrics, although they are dominantly foliated and the AMS minima are close to the respective bedding planes often exhibit well-defined lineations. Fold axes and AMS lineations are roughly N-S oriented, pointing to E-W compression (in present orientation), which was prevailing during the Latest Cretaceous-Eocene. Eventually, we can conclude that the joint interpretation of the structural and AMS results for the Sava Zone are without problems and suggest that the magnetic fabrics were imprinted during the first deformation phase affecting the flysch of the Sava Zone. In contrast, the acquisition of the paleomagnetic signals was governed by secondary processes, which could have affected the flysch before or after the general CW rotation of the Vardar Zone. This ambiguity leaves ground for alternative interpretation of the paleomagnetic results, which are either a CCW rotation connected to the thrusting of the flysch of the Sava Zone over the Western Vardar Zone or the absence of general vertical axis rotation after the magnetization of the flysch.

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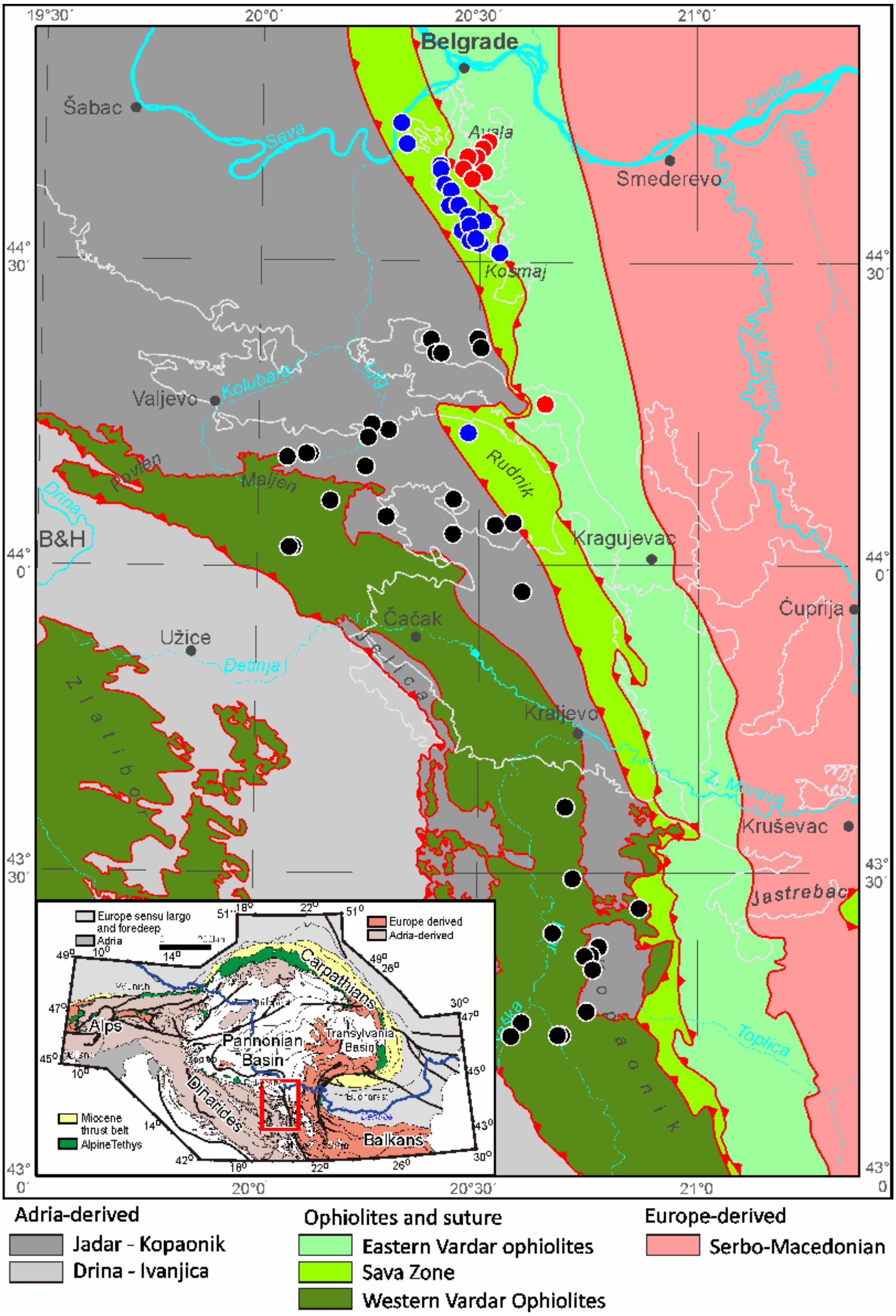

Figure 1: Paleomagnetic sampling localities/sites in the Vardar Zone: black dots - Western Vardar Zone, blue dots - Sava Zone, red dots - Eastern Vardar Zone. The inset shows the position of the study area within the Carpatho-Pannon-Dinaric-Balkan region.

Late Paleozoic strike-slip tectonics at the SW outskirts of Baltica versus oroclinal bending of Central European Variscides

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The European Variscan Belt sharply changes its trend in easternmost Germany and western Poland, where the ENE- to NE-striking structures are replaced by the ESE- to SE-trending ones. The structures of still another, NNE-SSW strike, take the lead, however, along the SE margin of the Bohemian Massif. The Variscan Belt seems, thus, to make nearly a U-turn, encircling the Bohemian Massif from the north. This has been explained for almost a century by assuming a 180° oroclinal loop, in which the Rhenohercynian and Saxothuringian tectonostratigraphic zones inarm the core of the Bohemian Massif. According to this classical view, the outermost tectonostratigraphic zone of the Variscan belt, the Rhenohercynian Zone, continues eastward in the deep substratum of the Permian-Mesozoic basin and reappears at the surface along the eastern rim of the Bohemian Massif.
Since the late 1970s an alternative view has gained an increasing attention that postulates a dextral transpressional regime during the final accretion of the Variscan terranes. This transpressional tectonic context is believed to have resulted from sublatitudinal, right-lateral displacements between Gondwana and Laurasia. Near the Carboniferous-Permian boundary, Gondwana decoupled from the newly formed European Variscan Belt and proceeded westward, toward the southern edge of the Laurentian segment of Laurasia, owing to the development of the Appalachian subduction system. Concomitantly with the peak of the Alleghanian orogeny during Early Permian, the European Variscan Belt experienced a cross-cut of its major tectonic zones along a set of dextral strike-slip faults.

In this study, we investigate directions and continuity of structural trends in the external zones of the Variscan orogen in Poland and map a foreland extent of Variscan deformations using seismic, gravimetric-magnetic and borehole data. We also highlight structural similarities and differences between the sectors of the Variscan externides located on either side of the presumed oroclinal loop. These permit us testing of the orocline- vs strike-slip concepts and to develop an overall kinematic model for the NE Variscides.

Matched filtering of isostatic gravity, guided by results of spectral analysis, along with other derivatives of gravity and magnetic fields reveal a dominant WNW-ESE-trending pre-Permian structural grain in the external zones of the Variscan Belt in Poland. This trend is confirmed by regional distribution of dips in Carboniferous and Devonian strata that were penetrated by boreholes beneath Permian-Mesozoic sediments. Seismic constraints on the position of the Variscan deformation front come from (1) the GRUNDY 2003 seismic experiment, combining wide-angle reflection-refraction measurements with the near-vertical reflection seismics in central Poland and (2) PolandSPAN and POLCRUST-01 deep reflection profiles in SE Poland. The WNW-ESE structural trend in the Variscan foreland is parallel to a set of major strike-slip fault zones in the area that are considered to convey a significant dextral displacement between Laurasia and Gondwana. The revised position of the Variscan deformation front shows a similar, uninterrupted, generally WNW-ESE trend, up to the SE border of Poland, which indicates an initial continuation of the more internal Variscan zones into the area of the present-day Carpathians. The geometry of the Variscan deformation front along with the pattern of the Variscan structural grain are inconsistent with the idea of an oroclinal loop affecting the external, non-metamorphic Variscan Belt.

The Czech Geological Olympiad and International Earth Science Olympiad: the way to promote geoscience education

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The Czech Geological Olympiad (https://www.geologicka-olympiada.cz/) is a competition for elementary and secondary school students in geological sciences. The competition aims to raise students interest in geological disciplines and motivate them to study further in this field.

This competition is organized by Masaryk University and the Czech Geological Survey in cooperation with museums and other institutions in the regions. The first year of the competition took place in 2017, so this year, i.e. 2021, is already the fifth year. Now, it is sponsored by the Ministry of Education and it is included in the Excellence program of the Czech Republic.

The competition takes place in four rounds: school, district, regional and national. The last regular, i.e. third year (2019) was attended by 631 competitors from primary schools (category A) and 326 competitors from secondary schools (category B). National round winners in category B are invited to participate in International Earth Science Olympiad. Two successful students, Marek Pavlica and Pavel Trávníček, have already represented the Czech Republic as young geologists at the international level in 2019.

The International Earth Science Olympiad (IESO) was founded as one of the major activities of the International Geoscience Education Organization, which is affiliated to and sponsored by the International Union of Geological Sciences. By Roberto Greco (chairman of the IGEO), the organization aims to promote geoscience education at all international levels, encourage and develop public awareness of geoscience, especially among young people, and improve the quality of geoscience education over the world. The IESO is an annual competition for secondary school students (not older than 18 years). Each national delegation is composed of four students and two mentors. The latter must be specialists in Earth science and Earth science education and capable of serving as members of the International Jury (https://www.ieso-info.org/). The official language of IESO is English.

The competition for each participant consists of **written and practical tests** (WT/PT). The theoretical examination includes problems that are supposed to measure the participants knowledge and understanding of Earth science areas. The practical examination consists of tasks that are designed to assess participants abilities to carry out scientific investigations in Earth science inquiries. The examinations are prepared by specialists in Earth sciences and Earth science education, who also provide solutions and evaluation guidelines.

The IESO is the only international Olympiad that includes an **International Team Field Investigation** (ITFI). Team investigation is based on a group solution of the problem in the field and oral presentation of its results to the evaluation committee. Each team consists of students from different countries. Participants should work together during experimental and/or field tasks and will be graded together as a group. Thus, ITFI turns out to be a special IESO tool to encourage friendly relationships among young learners from different countries and to promote international cooperation. Besides that, an **Earth System Project** (ESP) is arranged by the same student's groups. The project consists of theoretical analysis of a given topic and its group presentation in the form of posters, including poster sessions with the evaluation committee. As with ITFI, students are graded together as a group. In this way, both of these categories, ITFI and ESP, prepare competitors for scientific conference sessions.

The **13th International Earth Sciences Olympiad** took place from 26th August to 2nd September 2019 in Daegu, South Korea. The competition was attended by 43 teams with 163 students, 18 guest students, 84 mentors, and 55 observers. The Czech delegation is usually represented equally by two winners of the Geological and the Geographic Olympiads and by two mentors – geologist and geographer. The Czech Republic team won all kinds of medals in the theoretical and practical examinations category. Marek Pavlica, who won the gold medal for the Czech Republic, excelled in his knowledge and practical skills. Another member of the team, Pavel Trávníček, also won the Gold Prize in the ESP category. The other two silver and one bronze prizes were won in the WT/PT and ESP categories. Only Japan, Korea, Taiwan, and the United States won more gold medals than the Czech Republic.

Last year, the international competition IESO was canceled due to the pandemic situation, and this year's event organized by Russia is held online remotely (14th IESO, 2021). Due to the distance realization, the competition categories were changed. In the competition of individuals, it will be the so-called **Data mining** category with the use of public data servers. In the team competition, the research will be carried out both by national teams (**National Team Field Investigation** category) and international teams (**ESP**). A new category will also appear. On one hand, it's the **Mission to Mars**, on the other, **The Earth System Pledge** (i.e. how students are going to use their knowledge and skills in the future). The traditional final category **IESO Art and Science - Sharing of Earth Systems Art and Creativity** has an entertaining form.

Future IESO will take place in China (15th IESO, 2022). However, tectonic knowledge and skills are still missing. Therefore, we encourage you to join your national teams in IESO as well. For more information visit http://www.ieso-info.org/

Does the Grójec Fault (eastern Poland) coincide with an ancient plate boundary between Fennoscandia and Sarmatia?

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The Grójec Fault is one of the most conspicuous geophysical discontinuities within the SW margin of the Eastern European Craton (EEC) that is imaged by geophysical (magnetotelluric, gravity) data. This discontinuity correlates with a fault zone whose Late Cretaceous activity is documented by seismic and well data. Although the earlier history of the Grójec Fault is poorly constrained, the observed correlation between the position of the fault and the northern limit of Ediacaran sediments covering the SW slope of the EEC suggests its activity already in the Neoproterozoic.

Some recent studies on the structure of the EEC suggest that the Grójec Fault is located on the extension of a collisional suture between Sarmatia and Fennoscandia, two microcontinents forming parts of the EEC. Sarmatia and Fennoscandia collided with each other in the Paleoproterozoic (about 1.8 billion years ago), assembling at that time, together with Volga-Uralia, the EEC. The collisional suture of Sarmatia and Fennoscandia, if preserved until today, should be a broad structure reaching down to the base of the lithosphere.

To study the structure of the Grójec Fault Zone, we use magnetotelluric data combined with gravimetric and magnetic anomaly maps as well as seismic and well data. Our integrative interpretation of potential field data show that the Grójec Fault coexists with a major geophysical feature extending perpendicular to the Teisseyre-Tornquist Zone on its both sides and continuing eastward beyond the Polish border. Deep seismic reflection profiles of the PolandSPAN survey, oriented at a right angle to the Grójec Fault, provide evidence for its protracted Palaeozoic activity. The results presented here will provide input for further study including quantitative analysis of potential field data and building of 3D lithospheric-scale model.

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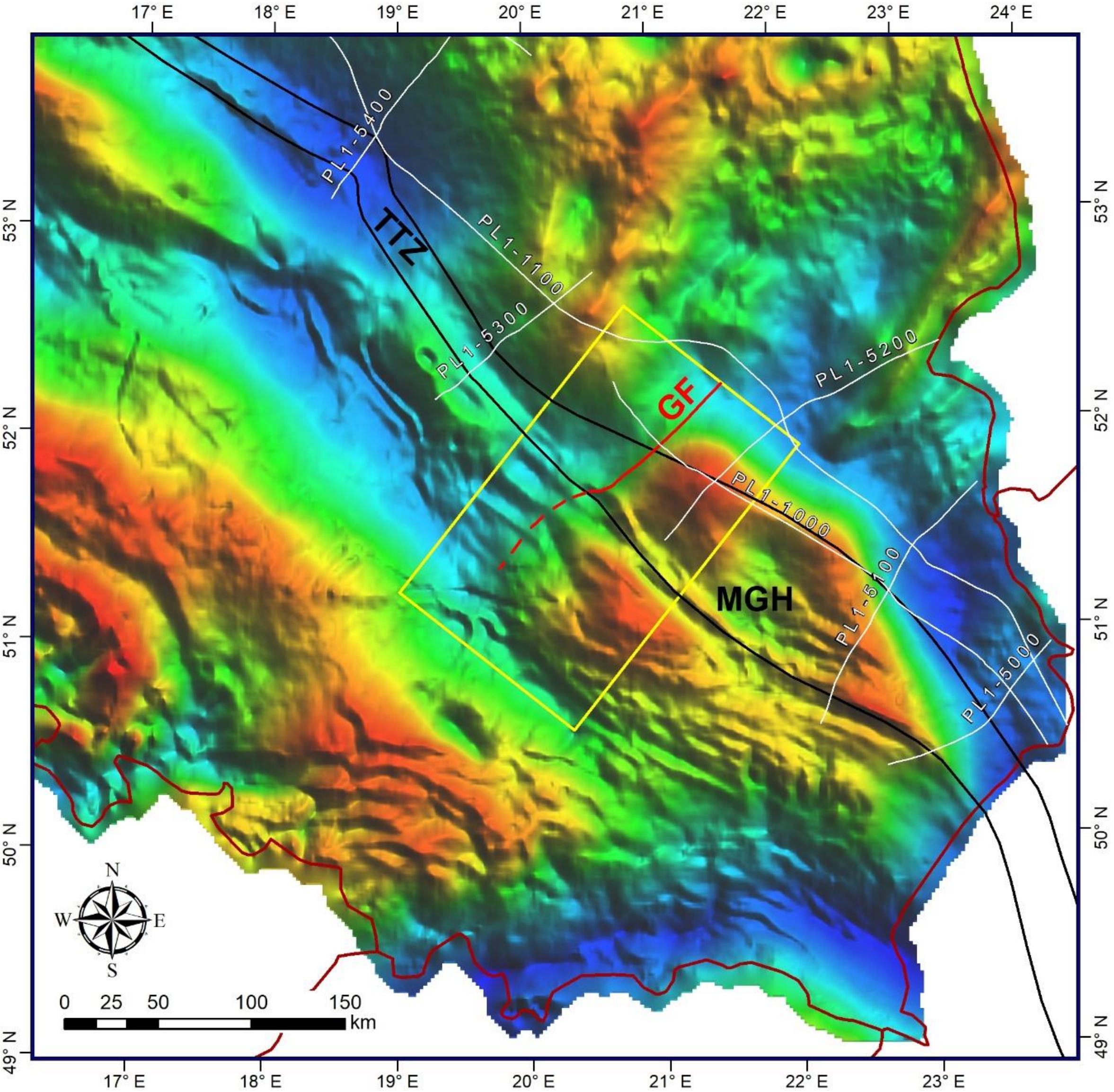

Figure 1: Location of the study area on the background of the Bouguer gravity. The study area is marked with a yellow rectangle, GF – Grójec Fault (red line) with its hypothetical extension SW of the Teisseyre-Tornquist Zone (dashed line); MGH – Małopolska Gravity High; TTZ – Teisseyre-Tornquist Zone (black lines); White lines show the location of the PolandSPAN seismic experiment.

Description of an atypical klippe near Revišné (Pieniny Klippen Belt, Western Carpathians)

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Pieniny Klippen Belt (PKB) is a long mélange zone situated between the internides and externides of the Western Carpathians. Its complexity is reflected in numerous unsolved questions within the sedimentary units of PKB and in the difficulty of paleogeographical reconstruction. During geological mapping, in the western Orava part of the PKB near village Revišné, an interesting klippe was described. The klippe consists of several lithostratigraphic units. In the middle part of the hill crest, synsedimentary Krasín Breccia outcrops. It is the first occurrence of Krasín Breccia found outside the middle Váh Valley. The top and the upper part of the hill consist of massive white crinoidal limestones of Smolegowa Limestone Formation with no visible brecciation (Bajocian age). Red to orange crinoidal limestones outcrop below. They belong to the Krupianka Limestone Formation (Bajocian age). All these formations belong to the Czorsztyn Unit of the PKB. After several meters of covered sequence, the lowermost part of the hill consists of beds of Kimmeridgian to Albian in age. The succession starts with red nodular to pseudonodular limestone (Czorsztyn Limestone Formation), passing to greenish-grey nodular limestone (Revišné Limestone), gradually continuing to white micritic limestone, partially spotted, of Biancone facies (Pieniny Limestone Formation). Stratigraphically higher, this formation becomes more marly and passes to grey spotted marlstones (Kapuśnica and Wronine formations). The key part of the section which would expose Callovian-Oxfordian strata is covered. The lower part of the section displays succession which is by no means typical for the Czorsztyn Unit. Hauterivian to Albian sediments are preserved, whereas in the Czorsztyn Unit it is known that they are usually entirely missing due to emersion and karstification. Moreover, the character of the Tithonian-Lower Cretaceous limestones is different from those which are typical of the Czorsztyn Unit. Despite of incompleteness, the marly character and the condensed succession indicate, that the lower part of the section may belong to the Grajcarek Unit (Šariš Unit), which is considered to be the most extraneous of all the Oravic units. The presence of Grajcarek Unit in the Orava part of PKB has not yet been described. The whole section represents a contact of two klippen units which can be interpreted as tectonic, i.e. overthrust. Sedimentary contact is very unlikely. Considering tectonic contact, we must note that the bedding of the upper and middle parts of the klippe (Czorsztyn Unit) is not visible and its present tectonic position is thus unclear. The succession belonging to the Grajcarek Unit is tectonically overturned. Therefore, there are two alternatives as to the origin of their present thrust position: 1) Grajcarek Unit was thrust onto the Czorsztyn Unit and later both were overturned; 2) Czorsztyn Unit was thrust over the already overturned Grajcarek Unit.

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Granitoid rocks of the Fabova Hoľa Massif, Veporicum

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The Fabova Hoľa Massif and its surroundings belong to the Veporic Unit, Inner Western Carpathians, Slovakia. The structure of this part of the Veporic Unit consists of medium- to high-grade metamorphic rocks intruded by Variscan granitoids, and the basement rocks have a Permian-Triassic sedimentary cover. The basement and cover rocks underwent Alpine (Cretaceous) tectono-metamorphic overprinting in higher greenschist facies medium pressure conditions.

The granitoid rocks of the Fabova Hoľa Massif are represented by these basic lithological types: medium- to coarse-grained, biotite (meta)granodiorites of the Vepor and Ipeľ types, and (meta)tonalites of the Sihla-type, with hypidiomorphic to homogeneous granular texture. The metamorphic-mylonitic texture is grano-lepidoblastic to lepidoblastic with blastomylonitic foliation. Primary magmatic minerals include quartz, plagioclase (oligoclase, replaced by fine-grained white mica), K-feldspar, sagenitic biotite (annite, locally baueritized and chloritized), possibly also muscovite and accessory zircon, fluorapatite, monazite-(Ce), xenotime-(Y) and Fe-Ti oxide. Moreover, a newly formed and recrystallized mineral assemblage includes quartz, albite, phengitic muscovite, epidote to clinozoisite, Ti-depleted biotite and muscovite ± garnet, tourmaline, hingganite-(Y) and hellandite-(Y). The dominant Vepor-type includes white phenocrysts of K-feldspars with an average size of 3-4 cm. A spatially minor is the Ipeľ type represented by typical pink phenocryst of K-feldspars with an average size of <3 cm. The non-porphyric variety typically occurs on the summit of Fabova Hoľa. These (meta)granitoids represent foliated blastomylonized porphyric metagranite. Rock-forming minerals of the Sihla type tonalite include euhedral to subhedral, locally porphyritic plagioclase as the most common mineral. Rare subhedral to anhedral interstitial perthitic K-feldspar, anhedral quartz, subhedral biotite, and locally also secondary (post-magmatic) anhedral muscovite and chlorite. Accessory minerals comprise large brown tabular prismatic-dipyramidal titanite, apatite, zircon, allanite-(Ce), epidote, magnetite, ilmenite, rutile and pyrite. The chemical composition of all types reveals the slightly peraluminous to metaluminous composition with A/CNK and A/NK ratios range from 0.99 to 1.01 and 1.69 to 1.72 respectively.

The Sihla tonalites are characterized by higher contents of Ca, Mn, Fe, Ba, Sr, and P compared to the S-type granites. The whole rock REE patterns are steep (La/Yb_N=10–48) with slightly negative Eu anomaly (Eu/Eu*=0.74–0.85). In general, they show an I-type calc-alkaline affinity. The isotope dating of Sihla-type tonalites gave 356 ± 2 Ma in-situ zircon magmatic age and 351 ± 6.5 - 344 ± 12 Ma in-situ titanite early post-magmatic age.

The investigated Vepor and Ipeľ varieties have high SiO_2 values (66.6 to 74.7 wt.%), Al_2O_3 (14.0 to 17.0 wt.%) and Na_2O+K_2O-CaO (4.2 to 7.9) and low TiO_2 (0.05 - 0.53 wt.%), P_2O_5 (0.04 to 0.2 wt.%) and moderate $FeO_{tot}/(FeO_{tot} + MgO)$ (0.70 to 0.79). Their A/CNK and A/NK ratios range from 1.0 to 1.2 and 1.2 to 1.6, respectively, and correspond to peraluminous composition. Trace-element geochemistry shows an enrichment in Ba (390 to 1180 ppm) and Sr (230 to 400 ppm) and variable REE+Y (50 to 350 ppm), and Y (8 to 20 ppm). The pronouced Eu negative anomaly indicates the fractionation of feldspars. The concentration of light elements shows an enrichment especially in B (~15 to 20 ppm) and Be (2 to 4 ppm).

In general, the granitoids show an S-type or hybrid S/I-type affinity and are characterized by calc-alkaline compositions and low contents of Mg, Ca, Sr, Ba, Zr and REE when compared with I-type granites. Some analyses anomalously fall into the A-type granitoids due to synmetamorphic gain of alkalis. The geochronological data of 355 ± 1.9 Ma obtained by in-situ Th–U–total Pb dating of monazite-(Ce) represent magmatic age of the granitic intrusion emplacement during the main stage of Variscan plutonic activity in the West-Carpathian Veporic crystalline basement. The saturation thermometry of Zr (I- and S-types) indicate a crystallization temperature in the range of 680 - 800 °C. A systematic decrease of temperature with increasing SiO_2 content indicates the fractionation towards more evolved peraluminous S-type varieties. More differentiated members with a higher SiO_2 content have apparently lower Zr content and higher content of alkalis. While the Vepor and Ipeľ types show a negative initial $\varepsilon Nd_t < -2.0$, the Sihla tonalites are rather depleted compared to them, with $\varepsilon Nd_t = -1.8$ to -0.1. This suggest the I-type isotopic signature for Sihla tonalites and a hybrid S/I-type isotopic signature for Vepor and Ipeľ types.

The formation of studied rocks is closely related to an anatectic event constrained in the hosting metamorphics at ca. 370 Ma by zircon U/Pb dating. They may be related to Variscan arc-type granitoids of the West-Carpathian crystalline basement.

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Structural controls of fenitic alteration in the Bükk Mts, NE Hungary

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The structure of the Bükk Mts. was formed as a result of a polyphase deformation history. Successions ranging from the Carboniferous to the Jurassic, mostly of Dinaric analogy, are uplifted and exposed here surrounded with the Cenozoic sediments and volcanics of the Pannonian Basin. The existence of a previously unknown HFSE (Nb, Ta, Th, Zr, Y and REE except Eu) enrichment was found in the southeastern part of the Mts. during a geochemical survey made in the frames of the CriticEl project in 2014. Mineralogical and geochemical tests done so far show that the process producing the features is potassic fenitization, a metasomatic alteration characteristic for the contact aureole of alkaline magmatic (mainly carbonatite) bodies. On the other hand, affected rock bodies are siliciclastic sedimentary or metavolcanic beds interbedded in thick limestone formations, and no outcrop of any magmatic body corresponding to a potential source was found.

The eastern part of the Bükk Mts. is divided into three major structural units bordered by SE-NW to E-W striking, steep strike-slip fault zones. The stratigraphy of these units overlaps, but deformation style of an early, ductile phase is different and, according to this, limestone, siliciclastic and metavolcanic formations represent different tectofacies in each. Boundary zones comprise several minor fault blocks derived from both sides, stacked in some cases in an alternating order.

Mapping supported by gamma-spectrometry located fenitized rock bodies in two different groups within the northern and southern boundary zone of the Central Bükk Unit, respectively. In the South, rocks from both units were affected by the alteration. The mineralization overprints the fabric formed during the early phase deformation, but younger faults dissect the mineralized bodies. The most plausible model for this situation is an alkaline (possibly carbonatite) intrusion in the root zone of the strike-slip faults, from which the alkaline fluids ascended in the limestone of the damage zones to relatively large distances without significant reaction with carbonate minerals.

Considering the structural constraints and published radiometric ages, possible time interval for the alteration extends from the Late Cretaceous to the Early Paleogene. According to the published models for the tectonics of the Carpathian Basin, the pre-Cretaceous rock assemblage of the Bükk was not in its present environment in that time, being transported to NE along the Mid-Hungarian Mobile Belt. Therefore, there is a chance that magmatic sources having produced the alteration are not in the close vicinity of the present-day Bükk Mts, and may be hidden in the basement of the Pannonian Basin.

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Petrofabrics of ignimbrites using the anisotropy of magnetic susceptibility: implications to the evolution of the late-Variscan Tharandt Forest Caldera (NW Bohemian Massif)

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Ignimbrites are deposits of pyroclastic density currents composed of volcanic ash, pumice/fiamme, and juvenile and lithic clasts. The rock-magnetic and paleomagnetic methods are commonly used to recognize flow directions, volcanic source area(s), and emplacement processes. Magnetic petrofabrics are usually investigated by the anisotropy of magnetic susceptibility (AMS) in combination with the field, petrographic and magnetic-mineralogy research. Here, we use the conventional in-phase AMS (ipAMS) along with the relatively new out-of-phase AMS (opAMS) technique to interpret the internal architecture and emplacement dynamics of the Tharandt Forest Caldera (TFC).

The late-Carboniferous TFC (NW Bohemian massif) includes ~50 km² collapse structure that was emplaced into the Neoproterozoic to Early Palaeozoic crystalline rocks. Main rock units consist of the pre-caldera Niederbobritzsch pluton, two major facies of intra-caldera rhyolite ignimbrites (caldera fill) and microgranite ring dykes. On most outcrops, the ignimbrites contain quartz and feldspar juvenile clasts, flattened fiamme and various volumes of lithic clasts embedded in an ash matrix with an apparent eutaxitic microstructure. The ignimbrites yield quartz-rich and quartz-poor textural facies. This central body is delineated by porphyritic microgranite ring dykes. The macroscopic flow foliation defined by the shape preferred orientation of flattened fiamme, and K-feldspar phenocrysts vary greatly among the studied outcrops. In many places, however, the ignimbrites appear rather isotropic. Therefore, a combination of field structural mapping and magnetic petrofabric analysis is used to detect the structural inventory in the ignimbrites and porphyritic microgranite.

Alternating field magnetic susceptibility can be decomposed into an in-phase and out-of-phase signal; the latter has a phase shifted of 90° from the alternating magnetization field. Their anisotropic behavior then corresponds to ipAMS and opAMS, respectively. The tensor of ipAMS results from the contribution of all minerals in a rock sample (ferro-, para- and diamagnetic), whereas the tensor of opAMS corresponds only to a certain fraction of ferromagnetic minerals and is zero for paramagnetic, and diamagnetic phases. Thermomagnetic curves (k_m–T) indicate the dominant mineral(s) carrying the AMS signal. Frequency-dependent susceptibility (χ_{FN}) detects the presence of ultrafine superparamagnetic particles.

We collected 295 specimens from 19 sites (~16 specimens per site). The bulk susceptibility (k_m) varies from 39 to 5750 × 10^{-6}; out of these 35 % and 65 % of specimens yielded ferromagnetic (group 1) and paramagnetic values (group 2), respectively. Only two sites have susceptibility lower than 100×10^{-6}. The thermomagnetic curves of group 1 indicate the dominant low-Ti titanomagnetite, while group 2 is characterized by a mixture of paramagnetic ferrosilicates with a slight contribution of fine-grained titanomagnetite, and titanohaematite. The low-susceptibility specimens yielded solely paramagnetic signal. The frequency-dependent susceptibility is rather low with a maximum of 1.5 % suggesting that the opAMS signal is carried by ultra-fine (frequency-dependent) particles. In general, the specimens with the higher k_m have also a higher degree of anisotropy (P parameter) and rather prolate-shaped AMS ellipsoids. Most of the sampling sites are dominated by the prolate-shaped fabric (site-mean shape parameter; $T<0$) with 1 % and 9 % of anisotropy. Plane-strain fabrics ($T\approx0$) with ~1 % of anisotropy occur in the case ring dyke and peripheral ignimbrite facies. The principal susceptibility axes of individual specimens are well clustered around their mean values at most sampling sites. In general, the dip direction of the opAMS magnetic foliations is rotated ~30° with respect to ipAMS foliation, whereas the dip is similar. The ipAMS magnetic foliation is usually parallel to the flow foliation. Both the flow and magnetic foliations (ipAMS) have various dips from subhorizontal to subvertical attitudes. The orientation of flow foliation, magnetic foliations, and lineations (ipAMS) vary greatly across the studied area.

The preliminary interpretation of this dataset suggests that we deal with strongly welded ignimbrites deposited from high-energetic, turbulent pyroclastic density currents within the collapsed caldera. This environment implies that after the emplacement, these ignimbrites underwent a high degree of welding. Our findings may, however, be challenged by several issues. (1) Given the low difference in outcrop elevation across the studied area, one cannot distinguish between structural levels of ignimbrite cooling units, which can yield different structural data. (2) No data constraints on pre-ignimbrite paleorelief are available to infer its influence on fabric orientation and AMS parameters. (3) Presence of single-domain state magnetic particles that could produce inverse magnetic fabrics in fine-grained volcanic rocks may alter our data interpretations. These issues will be discussed during the conference and supported by other AMS data from newly sampled outcrops, anisotropy of anhysteretic remanent magnetization data, and optical electron microscopy.

Salt tectonics in the Inner Western Carpathians (Silica Nappe, Aggtelek Hills): investigating the role of inherited Triassic salt structures during the Alpine deformation

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The Permian to Lowermost Triassic Perkupa Evaporite forms the base of the Silica Nappe (uppermost tectonic unit of the Aggtelek Hills, Inner Western Carpathians) and played the role of the main detachment level during the Cretaceous nappe stacking. Regionally, the Silica Nappe is one of the most enigmatic tectonic units of the Alpine-Carpathian area as up until now, it had many unanswered structural problems, like do the three or four different folding directions necessarily suggest multiple folding phases, how to solve the problem of extreme thickness changes in pre-orogenic sediments or why are young-on-older contacts so frequent in the area. Furthermore, several previous studies suggested that there may be salt diapirs rooting in this evaporitic detachment level but their role in the evolution of the Silica Nappe has not been studied in details.

In this study new approaches were applied in order to explain the abovementioned questions and to understand the deformation of the problematic Aggtelek Hills. Detailed geological mapping and structural analysis resulted in the recognition of extensive salt tectonics in the Inner Western Carpathians. Field results showed that not only simple salt diapirs but also map-scale salt walls were present in the southernmost part of the Silica Nappe. The observed onlap surfaces on the salt flaps and the extreme thickness changes within the Lower Triassic formations suggested that these salt structures originally formed syn-sedimentary with the respect to the Early Triassic sedimentation. Starting probably from the latest Early Triassic, sedimentation occurred in minibasins, the evolution of which was controlled by the continuously growing salt structures. Salt movements were coupled with doming and drag folding along the salt structures that resulted in slumping and syn-sedimentary normal faulting in the sedimentary cover.

These pre-existing salt structures and normal faults strongly influenced the geometry and kinematics of the subsequent Cretaceous deformation: the majority of shortening was localized at the salt walls and diapirs while the minibasins were left mostly unaffected. When the salt walls were squeezed, secondary salt welds formed that were now mapped as linear rauhwacke zones. Due to further shortening, the welds were reactivated as oblique thrust welds and the minibasin borders evolved into young-on-older thrust contacts. After peeling the effects of evaporite deformation off the Cretaceous shortening, the main tectonic transport direction was estimated to be towards S-SE.

Consequently, the structural evolution of the Silica Nappe is much more complex than previously thought but many long-standing problems could be explained by considering structural inheritance and bringing pre-orogenic salt tectonics into the interpretation. Nevertheless, the Aggtelek Hills turned out to be a good area to further study the effects of inherited salt structures on the evolution of fold-and-thrust belts and to draw conclusions on how to separate salt-related folding from regular shortening related structures in poor outcrop conditions.

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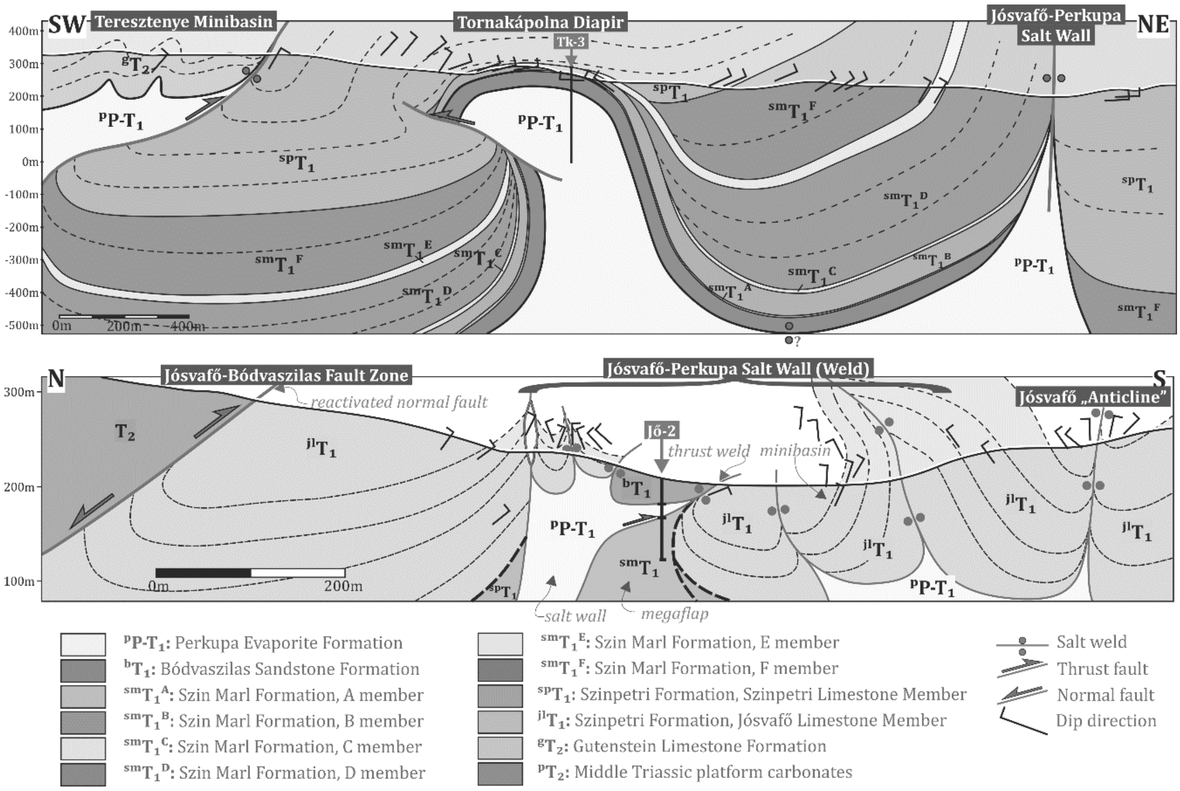

Figure 1: Cross-sections through the most important structural elements of the southernmost part of the Silica Nappe (Aggtelek Hills, Inner Western Carpathians): the young-on-older contact of the Jósvafő-Bódvaszilas Fault Zone; the Jósvafő-Perkupa Salt Wall that evolved into a secondary salt weld and reactivated as a dextral tear fault during the Cretaceous shortening; the Szövetény Diapir and the Teresztenye Minibasin.

Pressure-Temperature evolution of the Barrovian metamorphic rocks from the Isbjørnhamna Group, Svalbard Caledonides

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The Isbjørnhamna Group crops out in Wedel Jarlsberg Land, south-west Svalbard. Possible correlatives of these rocks may also occur farther south in Sørkapp Land. It is formed of a Barrovian-type series of metapelites which have been metamorphosed c. 640 Ma during the Torellian Orogeny and then overprinted during the Caledonian Orogeny. Although the Isbjørnhamna Group is important to understand Svalbard's regional geology and tectonic evolution, the rocks in question have not been studied in detail. The only pressure and temperature (P-T) estimates we know were obtained with petrogenetic grids (KFMASH system) and conventional geothermobarometry. To determine a comprehensive metamorphic history of the Isbjørnhamna Group, key samples have been reinvestigated with the most up-to-date petrological approach.

The studied rocks are garnet-bearing mica schists preserving four different parageneses containing: (1) chlorite and chloritoid, (2) staurolite, (3) both staurolite and kyanite, and (4) kyanite. Previous methods gave the following P-T conditions: ~580°C at 8-9 kbar for the garnet-staurolite schist, ~624°C at 6.6 to 8.7 kbar for the garnet-staurolite-kyanite schist and ~655°C at 11 kbar for the garnet-kyanite schist. The garnet-chlorite-chloritoid schist has not been studied before.

New phase equilibrium modelling using Theriak-Domino software in the MnNCKFMASHTO system indicates somewhat different P-T conditions than those obtained previously. For calculations of peak conditions, effective bulk obtained by removal of garnets cores compositions has been used. For the garnet-chlorite-chloritoid schist, isopleths of garnet and of white mica are cross-cutting in the stability field of both chlorite and chloritoid at ~540°C and 9.5-10 kbar. For the garnet-staurolite schist, garnet isopleths, as well as isopleths for white mica and biotite, are cross-cutting in the staurolite field at ~620°C and 7.5-8 kbar. Preliminary results for the garnet-staurolite-kyanite schist show that garnet isopleths are cross-cutting in the staurolite and kyanite stability fields at ~680°C and 7.5-8 kbar. Garnet is strongly retrogressed in the garnet-kyanite schist. Despite this, isopleths of white mica, biotite and plagioclase are all cross-cutting in the kyanite field at ~710°C and 8-8.5 kbar. The new results show that these rocks record distinctive stages of the Barrovian metamorphism, pointing to the prograde sequence going from the chloritoid to the kyanite zone mostly by an increase of temperature.

This study forms the base for filling the current gaps in understanding the regional geology of the Barents Sea region of the High Arctic. Detailed petrochronological and structural studies will follow to answer the remaining questions about the extent of the Isbjørnhamna

Group, exact timing of the metamorphism and the final exhumation process, which brought this unit to upper crustal levels.

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Open-source Radon Detector Concept for Tectonic Early Warning System

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As a major natural hazard, earthquakes are continuously being heavily investigated trough research. Still, one of the biggest challenges of seismic risk reduction is earthquake prediction method. Attempts for predicting these events in terms of epicentre, magnitude and date have traditionally relied upon geophysical methods such as seismology, deformation of the ground, electrical methods, etc. One of commonly used methods for earthquake prediction is measurement of radon emanation in soil and ground water in seismically active zones. Radon measurements for earthquake prediction require large network of the detectors that serve two purposes: as an earthquake precursor and to collect high amounts of data for further research as research in this area strongly relies on heavy statistical analysis. Radon detectors are expensive, and thus its price is limiting factor in size of detector network. Open-source software and hardware communities have proven to be extremely efficient in solving such cost related problems trough open hardware and computer software that is released under a license in which the copyright holder grants users the rights to use, study, change, and distribute the software and hardware design to anyone and for any purpose. Main goal of our research was to develop a concept of an open-source radon detector, and thus, potentiate the expansion of radon detection networks. Detector concept is based on a proportional counter which is a gas filled detector. There, gas is enclosed with two electrodes between which a voltage potential is applied. Incident radiation causes gas ionization and charge carriers move towards the electrodes due to an electric field between them. In proportional counters, the electric field is strong enough to enable secondary ionizations, which results in charge multiplication and a signal that is easier to measure. Charge multiplication in a proportional counter creates a output signal that is proportional to the absorbed energy of incident radiation, thus the origin of the name. This enables counting and energy resolving of the incident radiation. Detector system is consisting of three parts: open air proportional counter, detector electronics and forced air system. Body of the detector is designed to be 3D printable from ABS plastics and its electrodes made from noncorrosive metal foil. Electrodes are connected to detector electronics that include power supply, signal conditioning, acquisition, analysis and digital outputs. Digital output ensures easy implementation of communication system for sending data to the server while forced air system ensures precise airflow for continuous radon sampling.

The 29th December 2020, Mw 6.4 Petrinja Earthquake (Croatia): Geological Framework and Observed Coseismic Deformation Features

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On 29th December 2020, at 11:19:54 (UTC), the Mw 6.4 earthquake struck Petrinja, about 50 km southeast of the Croatian capital Zagreb. The day before the main event, two foreshocks (Mw 5.2 and 4.7, at 6:28 and 7:49, respectively) were recorded in the area, causing no significant damage. The largest aftershock (Mw 4.9) happened at 17:01 UTC, 6th January 2021, and was recorded on the temporary network installed just a day earlier. The 2020 Petrinja earthquake is one of the largest earthquakes recorded in Croatia since the instrumental recording began. The main event caused seven fatalities, thousands of homeless, and many heavily damaged or destroyed buildings and other objects.

Following the Mw 6.4 event, geoscientists conducted geological, geophysical, seismological, geodetic, and hydrogeological investigations. The Geophysical Department of the University of Zagreb has organized a post-event support survey collaborating with the Seismological Research Center of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale. Mitigation encompassed the installation of five seismic stations at the locations surrounding the epicentral area. For precise mapping of the Mw 6.4 Petrinja earthquake surface fault rupture and measure of coseismic deformation, we used the Differential Interferometric Synthetic Aperture Radar (D-InSAR) on the Sentinel-1 images. The coseismic interferograms show a dextral strike-slip deformation pattern with maximum surface displacements of 39 cm. For four months, geological fieldwork included data collecting and mapping the coseismic deformation features in the Petrinja fault zone. Field observations identified numerous geological features, e.g., liquefaction near major streams, gravitational slides, rotated gravestones, and seismically-induced opening of cover-collapse sinkholes in the villages of Mečenčani and Borojevići. Groundwater levels measured immediately after the mainshock were very high, probably significantly contributing to liquefaction and formation of cover-collapse sinkholes.

Fieldwork also shows that a total of 136 cover-collapse sinkholes were mapped by remote sensing and field mapping in the 4 km^2 area around Mečenčani and Borojevići villages, of which 91 opened due to the Petrinja earthquake series. Other sinkholes were opened before the earthquake since the area is historically known to be naturally prone to collapse of thick soil into underlying heavily karstified limestones. Since dozens exist near houses, geoelectric tomography was conducted to define geological settings up to 40 m depth and delineate safety from high-risk areas. The Petrinja earthquake series is still ongoing, but most earthquakes occurred following the mainshock's first weeks. During the first two months (December 28, 2020–February 22, 2021), more than 4300 earthquakes have been recorded.

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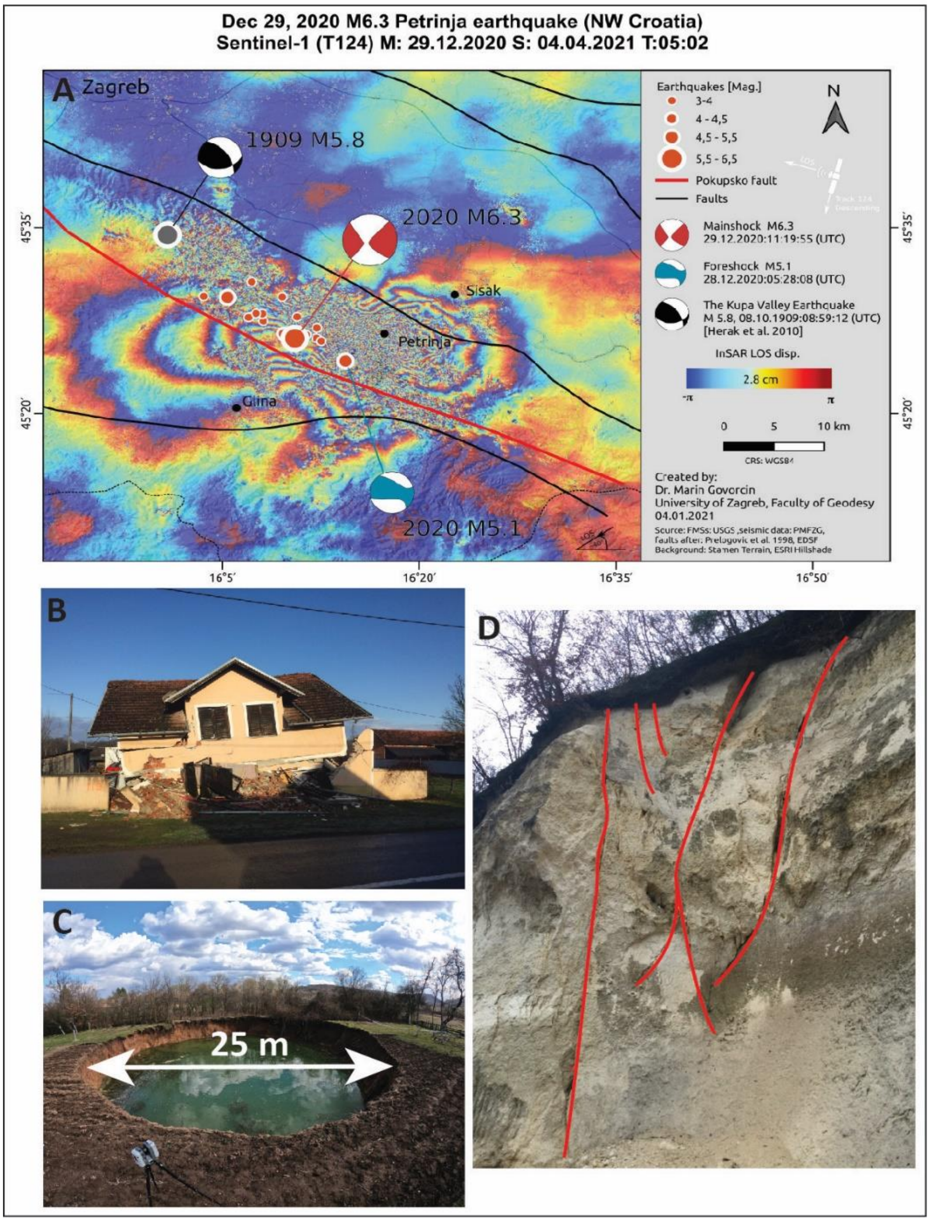

Figure 1: A) Intergerogram of the Sentinel 1 of the Petrinja Earthquake. B) Demolished house in Prekopa village near Glina town; C) Largest collapse sinkhole formed in Mečenčani village; D) Surface ruptures in the quarry of Badenian limestones in Župić Village near Petrinja city

Structural control and three-dimensional geological modelling of the epithermal Au-Ag deposit of Banská Hodruša (Štiavnica Stratovolcano, Slovakia)

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Neogene volcanism and back-arc related extension is the main area of epithermal deposits of low to intermediate sulphidation types in the Carpathian arc. The study mineralization occurs within the Štiavnica-Hodruša ore district in the central zone of the Štiavnica Stratovolcano of Miocene age.

The intermediate-sulphidation Au-Ag-Pb-Zn-Cu Banská Hodruša deposit is located in the middle of the central zone of the stratovolcano. This deposit at the Rozália mine represents a subhorizontal multi-stage vein system. A low angle normal fault zone (LANF) with the dip azimuth of 125° and generally flat, less than 30°, inclination hosts the mineralisation. LANF was newly identified during our research and it is the unusual structural setting of the deposit resulted in several unique characteristics, such as fluid properties of the hydrothermal system, distribution of ores and alteration patterns. LANF is related to processes of exhumation of subvolcanic granodiorite pluton. The mineralization is located in intensively altered pyroxene andesite of pre-caldera age. The thickness of the mineralized zone is typically tens of metres up to one hundred and has a tabular shape and gently dipping south eastward. LANF is characterised by normal faulting with the NE–SW strike of fault planes and complex structures among the fault damage zone. The Krištof type veins fill tension gashes, predominantly oriented in the NNE–SSW direction with moderate dip to the ESE. The Agnesa type veins occurs in a gentle dipping releasing bends predominantly at the roof of LANF, having the same age as the Krištof type veins. These veins are typically shallow dipping (less than 30°) with the dip direction south eastward.

Most probably, the slightly older kinematics is responsible for the formation of the Central Stockwork controlled by an NNW–SSE oriented σ_3 with the general strike in the WNW–ESE direction. This zone represents the initial phase of precious metal mineralisation in LANF and can be interpreted as a damage zone along the ramp fault.

Continuous mining, exploration and associated geological research provided large amount of data that is needed for construction of 3D geological model of the Banská Hodruša deposit. Input data for this model are provided by three datasets. First dataset consists of a database of lithological and geochemical data from drillholes. Second dataset is composed of adit data, which contains structural, lithological, and geochemical data. Third dataset is represented by the geological adit maps and sections. Given the above described dataset, 3D geological model of Banská Hodruša deposit was constructed by data and knowledge-driven explicit method. There are: i) Rozália vein system model; ii) andesite and porphyry intrusion models; iii) Base and top of LANF models; iv) Svetozár vein model; and v) Agnesa and Krištof vein system models (Fig. 1). The modeling area is subdivided on the western part (W of Bakali vein) and the eastern part (between Bakali and Terézia veins) based on input data type. General conclusions from the modeling are i) General gentle increasing in the dip angle of Rozália vein type towards Terézia; ii) Thickness of the vein-host andesites are greater in the W of the deposit than in the E, which reflects on vein size, thickness amount, and spatial distribution; iii) Vein sets defined by structural data are collative with vein sets defined by mineralogical features; iv) Based on structural settings it is possible to define multiple generations of porphyry intrusions; v) 3D geological model represents a solid base for further planning of research and mining activities as well as geological prospection of poorly investigated or uninvestigated areas.

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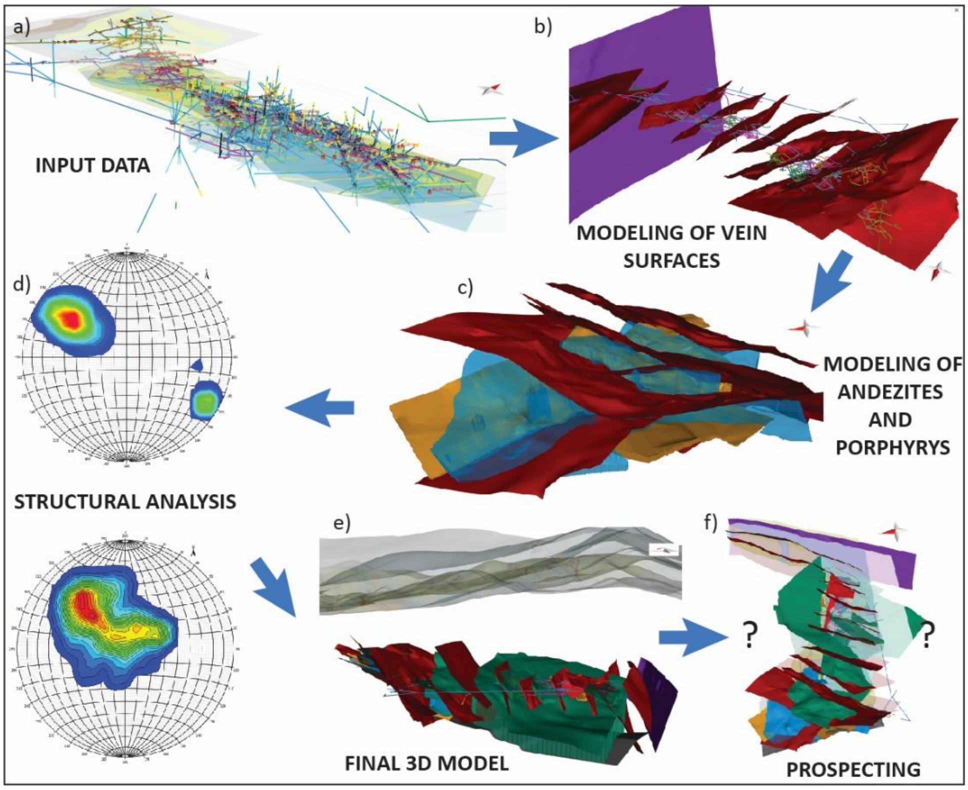

Figure 1: 3D structural modeling process of the Banská Hodruša deposit.

Deceptive zircon REE patterns and U-Pb dates from migmatite-hosted eclogites (Montagne Noire, France)

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Zircon REE patterns are widely used to attribute specific U-Pb dates to eclogite-facies metamorphism. Eclogites hosted in sillimanite-bearing migmatites in the Montagne Noire dome (French Massif Central) reached c. 750 °C, 21 kbar (pseudosection modelling and Ti-in-zircon thermometry) before significant decompression at high temperatures. Zircon crystals from the eclogites yield dates that spread from c. 360 Ma to a dominant data cluster at c. 315 Ma. Whatever their apparent ages, however, all crystals display identical REE patterns (no Eu anomaly, flat HREE), usually ascribed to eclogite-facies equilibration. In the absence of other criteria, none of these dates can be unequivocally attributed to the HP event. Using the results of a previously published Sm-Nd dating of garnet, and regional considerations, we interpret the 360 Ma date as the age of the eclogite-facies event. The 315 Ma zircon dates obtained from the enclosing sillimanite-bearing migmatitic rocks are interpreted as the age of the low-pressure high-temperature (LP-HT) metamorphism (~6 kbar, 730 °C). This strongly suggests that this date of 315 Ma obtained on some of the zircon grains from the eclogite has to be related to the LP-HT overprint and cannot therefore be attributed to the eclogite-facies metamorphism as previously suggested. It is inferred that during the post-eclogitic exhumation, eclogite-facies zircon grains recrystallized and underwent partial to total resetting of their U-Pb system, whereas the REE system remained mostly unmodified. These results caution against the use of REE patterns as the only criterion to associate a specific zircon age with HP metamorphism in eclogites occurring in migmatitic domes. Misinterpreted young ages may lead to inferring erroneous fast exhumation rates and consequently questionable geodynamic models.

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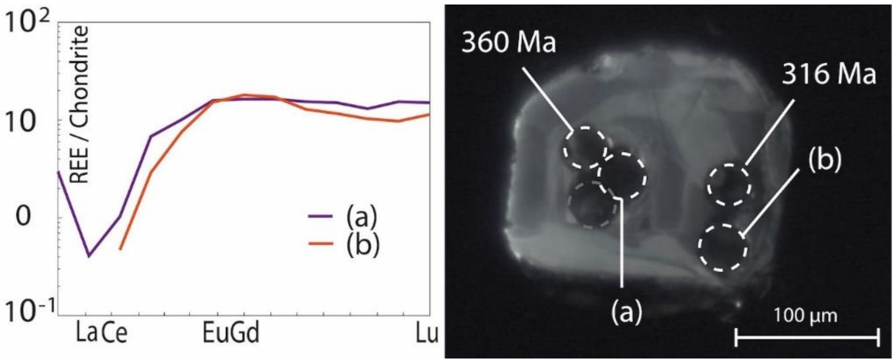

Figure 1: Absence of correlation between U-Pb dates and REE patterns. Zircon zones yield various dates, but similar REE patterns, typical for eclogite-facies equilibration.

Backstop-edge tectonics: The Pieniny Klippen Belt of NW Slovakia

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As a narrow but lengthy structural zone, the Pieniny Klippen Belt (PKB) forms a backbone of the Western Carpathian orogen. It separates and joins the Cretaceous basement/cover nappe stack of the Central Western Carpathians (CWC, Austroalpine tectonic system) and Cenozoic accretionary wedge of the External Western Carpathians (EWC, Flysch Belt, Pennine system). During development of the EWC accretionary wedge, the PKB occupied a position of the backstop in the rear of the wedge. In this tectonically exposed position, its original nappe structure was strongly modified by superimposed out-of-sequence thrusting, back-tilting, back-thrusting and along-strike transpressional and transtensional movements. In spite of ubiquitous occurrence of the characteristic Oravic units, the individual segments of the PKB and adjoining zones differ considerably in local structural patterns of the variably presented Oravic, “non-Oravic” and overstepping units.

The area concerned occupies the eastern, W–E trending part of the Varín (Kysuce), and the westernmost part of the Orava sectors of the PKB in north-western Slovakia. Both sectors are separated by the only important transversal structure in the PKB, the N–S striking Zázrivá–Párnica “sigmoid” with an apparent dextral offset of ca 6 km. The PKB structure is extraordinarily complicated in the Terchová–Zázrivá area of the Varín sector. In general, it resembles a complex, fan-wise asymmetric synclinorium with the subvertical northern limb and steeply north-dipping southern belt. Both limbs are formed by intricate systems of slices and fragments of Oravic units, frequently in abnormal positions. The central PKB zone is then occupied by obviously less deformed, but completely overturned north-dipping and very thick complex of Senonian calcareous turbidites of the Pupov Formation in the highest structural position. However, the tectonic affiliation of the Pupov Fm. remains questionable. Moreover, the easternmost part of the Varín sector is marked by the presence of another unit of problematic provenance named as the Kozinec Unit in this contribution. It is a continuous Jurassic to mid-Cretaceous deep-water succession with presence of some sedimentary formations that are rather typical of the “non-Oravic” (i.e. most probably Fatric nappe system of the CWC origin) than of the Oravic units (e.g. the Toarcian Adnet Fm., or the Albian–Cenomanian flysch formation). The Kozinec Unit forms a complex large-scale recumbent fold with an overturned, moderately north-dipping upper limb. Similarly as the Pupov Fm., the Kozinec Unit occupies a high structural position above the imbricated Oravic units, but both occur in distinct areas separated by an important WNW–ESE Ráztoky fault zone that is oblique to the PKB trend and shows a dextral offset. Thus, the logical solution that the Kozinec Unit is a Fatric element incorporated into the PKB structure along with its overstepping, Gosau-type Pupov Fm. cannot be confirmed by direct field evidence.

The western Orava PKB segment seems to be a prolongation of both the northern and southern, steeply north-dipping imbricated belts of Oravic units from the Terchová–Zázrivá region, which is lacking the central synform zone. The interconnecting Zázrivá–Párnica sigmoid appears not to be a distinct N–S trending fault zone, as usually assumed. Notwithstanding the poor outcrop conditions in an area covered by thick debris of Magura rocks and numerous landslides, it can be documented that it is rather an east-dipping, low-angle lateral ramp along which the Krynica Unit of the EWC Magura nappe group was thrust obliquely back over the PKB units. The latter were, in turn, thrust back over the frontal CWC units of the Malá Fatra Mountains. Hence, the Cretaceous nappe units and crystalline core of the Krivánska Malá Fatra Mts. are plunging eastward below the backthrust system of the Magura and Oravic units in the Orava PKB segment.

It is inferred that the structural complexities in the PKB and contiguous zones in the area concerned, but also in other sectors of the western PKB branch, were generated by the long-term structural evolution of the PKB positioned at the mechanical boundary between the rigid CWC block and the deformable accretionary wedge composed of sedimentary units scraped off the subducting Pennine oceanic and/or attenuated continental lithosphere. The wedge growth commenced by the latest Cretaceous to Eocene stacking of the Oravic nappes detached from a continental ribbon in the Middle Penninic position (a.k.a. the Czorsztyn Ridge) and continued by accretion of the Magura units during the late Paleogene. As the wedge grew, the Oravic and adjacent units were transferred from the wedge toe to its rear, where they were subjected to backward tilting and thrusting, and partially redistributed by along-strike slipping. Backthrusting of the PKB in the Malá Fatra area is probably the most extreme, estimated to at least 5 km. It affected not only the PKB itself, but distinctly also the adjacent zones of the CWC nappe stack, as revealed by one of the most conspicuous structure of the area – the Medzirozsutce south-verging reverse fault incorporating also sediments of the Central Carpathian Paleogene Basin.

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Influence of H_2O on deformation behavior and microstructure changes in Tana-quartzite

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Since quartz is among the most abundant minerals in continental crust and one of the first to show plasticity with increasing pressure and temperature, understanding its mechanical behavior is crucial for estimates on crustal strength and modeling of geodynamic processes. Since discovery of significantly lower mechanical strength of quartz as a consequence of H_2O presence in the crystal, remarkable amount of work has been done in order to improve the knowledge about processes and mechanisms responsible for the so called H_2O weakening effect. As the weakening effect depends on molecular H_2O, it is a disequilibrium weakening process that is difficult to incorporate into the existing flaw laws. In order to evaluate mechanical behavior of quartz in the presence of H_2O, deformation experiments were performed in the solid-medium Griggs-type apparatus in coaxial setting under controlled laboratory conditions, using very pure natural quartzite from Tana quarry (northern Norway). The behavior of samples with added H_2O in range from 0.1 to 0.5 wt%, as well as of as-is samples, was studied in 1) three series of shortening experiments at 900 °C, 1 GPa and constant strain rate of 10^{-6} s^{-1} reaching 30% strain, 2) six strain rate stepping experiments covering 10^{-5}, 10^{-6} and 10^{-7} s^{-1}, 3) two temperature stepping experiments covering 750, 850 and 950 °C and 4) two hot pressing experiments maintaining the starting experimental conditions for 14 hours. FTIR spectroscopy was applied to evaluate H_2O for its speciation, quantity and distribution. Microstructure examination was based on 1) optical microscope observation in cross-polarized light and with gypsum accessory plate, 2) CL imaging, 3) EMPA elemental mapping and 4) EBSD analysis.

Even though all as-is samples appeared to be the strongest compared to 0.1 and 0.2 wt% H_2O added samples, the strength difference is within the experimental error. In terms of samples with more than 0.2 wt% H_2O added, results are much more scattered in the stress-strain field and their general strength is ambiguous. Some of those samples showed distinctly weaker behavior, while another ones were stronger than as-is samples. As-is and 0.1 wt% H_2O added strain rate steeping experiments had shown surprisingly low stress exponent, with the highest value of 2.26. Temperature stepping experiments, within the same range, gave activation energy values of 177 kJ/mol and 198 kJ/mol. In all studied samples, the strain increases towards the sample centers exhibiting a significant grain size decrease from initial 250 – 300 µm. Three principal deformation mechanisms contributing to the bulk strain were identified: 1) crystal plasticity of original grains manifested by flattening, undulatory extinction, and development of subgrains, 2) cracking of the original grains demonstrated by fluid inclusion trails and minor grain offset and 3) dynamic recrystallization via subgrain rotation recrystallization indicated by misorientation analysis from EBSD data. Distribution of misorientation axes across the low angle grain boundaries of grains reconstructed from EBSD data revealed dominance of prismatic <a> slip system and less dominant rhomb <a> slip system. Regardless of added H_2O or as-is samples, most of deformed original grains showed relative H_2O concentration between 0 and 400 $H/10^6Si$, implying significant decrease of H_2O content from the original 600 to 2000 $H/10^6Si$ measured in undeformed grains. Average H_2O concentration in grain boundaries is increasing corresponding to the trend of H_2O adding. Plasticity is most visible in CL-images, as well as higher degree of grain fragmentation and crack density in samples with more H_2O added. The ubiquitous presence of fluid along the grain boundaries, demonstrated by FTIR results, may have facilitated sliding along grain boundaries which, in turn, could explain the low stress exponent derived from our strain rate stepping experiments.

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Various deformation mechanisms and recrystallization conditions of Meliatic metacarbonates

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During deformation, the rock adapts to physical conditions and recrystallization. There are several mechanisms, which differ from each other by the conditions under which they occur and at the same time by the resulting structures in the rock. The resulting deformation microstructures in carbonate rocks can provide important information for the detection of deformation development in various tectonic events. This work is devoted to the metacarbonates from the Meliatic Unit, which is part of the suture-accretion complex after closure of Meliata Ocean. Based on the observation of microstructures, the samples were divided into four groups that reflect different P-T conditions, the deformation mechanism and possibly also deformation stage. Subduction processes associated with the rock complexes of the Meliatic Unit (especially Bôrka Nappe) are well known. The features of these processes and thus the deformation and metamorphosis under conditions of high pressures and relatively lower temperatures (D1) are best preserved in olistolith bodies. This feature is related to their location in weakly metamorphosed pelagic sediments, where they were probably protected from more pronounced strain transformation. However, the D1 features were also preserved in positions that later underwent post-subduction deformation and metamorphic processes. The deformation stage associated with subduction is characterized by dynamic recrystallization of carbonate rocks at relatively higher temperatures. Under these conditions, dynamic recrystallization took place by the mechanism of Grain Boundary Migration (GBM), which caused the formation of a characteristic microstructure. The influence of higher temperature during deformation is also documented by the character of twin lamellae, which are coarse, often curved and, like the calcite grains themselves, show signs of dynamic recrystallization. Another feature that indicates deformation under relatively higher temperatures is the elongated grain shape, which could indicate the presence of aragonite as a higher temperature allotropic modification of calcite. The next phase after the closure of the Meliata Ocean and subduction was the exhumation of Meliatic complexes by ongoing compression tectonic processes (D2). The formation of the accretion complex is characterized by significant imbrication and the division of Meliatic units into several slices, often together with the overlying Turnaic Unit. These events are well visible in their current position in general, as well as in the internal structure of the rocks. As a result of these processes, domains of significant shear deformation have formed in carbonate rocks. The processes associated with the formation of the accretion complex are manifested as narrow domains. They are characterized by a strong shape orientation of calcite grains and often by a reduction in grain size. The chronologically next stage (D3) was connected with the process of release and exhumation of the Veporic core complex associated with sinistral shear zones. These processes had an obvious effect on the character of carbonates in the outermost parts of the Bôrka Nappe. This release provided space for the emplacement of underlying granite intrusion (Rochovce granite), which significantly affected the overlying complexes. As a result of intrusive activity, the complexes at the Veporic-Gemeric contact affected by contact metamorphosis or by the influence of hydrothermal activity were considerably modified. Due to the action of hydrothermal activity, the carbonate complexes in this area were statically recrystallized, thus creating the so-called foam structure, i.e. completely recrystallized marble but without signs of dynamic recrystallization. The formation of this type of microstructure is associated mainly with higher temperatures without the influence of deformation, especially in the areas of exhumation of the core complex. The calcite grains are approximately the same size with sharp borders. Process of the Veporic exhumation was connected with final stage of nappe stacking in this area. This process (D4) is also recorded in the microstructures of the underlying Meliatic metacarbonates, and it can be observed in more or less all localities. The gradual displacement and tectonic processes associated also with emplacement of the Silica Unit caused a dynamic recrystallization of the underlying complexes, which is manifested by bulging as the main deformation mechanism, which makes possible to assume very low temperature conditions. Dynamic recrystallization by bulging is manifested by the indentation or formation of newly formed small grains along the edges of the original calcites. The recrystallization process is accompanied by the formation of very thin twin lamellae, which is equally visible at all localities and also indicates low-temperature deformation.

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Mutual interaction of felsic granulite with cm-scale mantle xenoliths in HT conditions (St. Leonhard granulite massif, Lower Austria)

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Centimeter-scale fragments of (ultra-) mafic lithologies - garnet pyroxenites and peridotites - are present in the St. Leonhard granulite massif (Lower Austria) where spectacular reaction textures can be observed at the contact of these contrasting rocks. This allows to study the diffusion-related processes that appear at their borders on micro-scale.

The host felsic granulite is composed of K-feldspar, plagioclase, quartz, garnet and orthopyroxene, presence of garnet clusters with spinel and corundum inclusions indicate that kyanite used to be a part of the mineral assemblage. Garnet pyroxenite is composed mainly of garnet and clinopyroxene, garnet is partially replaced by amphibole-plagioclase symplectite with minor biotite. The xenolith and is surrounded by ~2 mm thick layer of orthopyroxene-plagioclase symplectite. This corona shows zoning with decrease of XMg in orthopyroxene (0.76→0.72) and increase of anortite content in plagioclase (47→35%) towards the felsic granulite. Garnet grains often continue across the border of the pyroxenite to the symplectite corona, implying that the symplectite layer was formed at the expanse of the pyroxenite rather than to growth from its surface towards the felsic matrix. Such garnet shows strong XMg modification from 0.72 in the xenolith to 0.48 at the contact with the quartz-rich matrix. Rare peridotite xenoliths composed of olivine are surrounded by an orthopyroxene corona sometimes accompanied by phlogopite. This layer shows pronounced zoning defined by XMg decrease (0.88→0.75) and Al increase (0.05→0.12 apfu) from olivine to the granulite. In the vicinity of the mafic xenoliths, ~2 mm wide zone depleted in K-feldspar occurs, indicating diffusion of K from the granulite to the mafic xenoliths, which is consistent with growth of amphibole and biotite inside of the coronas and xenoliths.

Assuming that the orthopyroxene-plagioclase symplectite layer is formed at the expanse of the pyroxenite as a consequence of metasomatism at the contact with the felsic host, the bulk rock chemistry of both primary and modified lithologies was compared. The most important change is noticeable loss of Ca accompanied by gain of Si. Additionally, the corona is slightly enriched in Na and Fe and depleted in Mg.

The P-T conditions of the interaction were deduced from P-T pseudosection constructed for the composition of the host felsic granulite with well equilibrated mineral assemblage (garnet, K-feldspar, plagioclase, quartz and orthopyroxene) giving ~ 870–970 °C and 11–13 kbar.

Based on the conclusion that there was considerable influx of Ca from the mafic xenoliths to the felsic matrix, P-X pseudosection was constructed showing the effect of Ca-loss on the mineral assemblage of the orthopyroxene-bearing felsic granulite. This diagram is showing that decrease of CaO contenty by c. 40% (2.94 to c. 1.80 mol. %) leads to destabilisation of orthopyroxene and formation of kyanite in the P-T conditions of interest. This is consistent with the observation of kyanite pseudomorphs (garnet clusters with spinel and corundum inclusions) indicating that the orthopyroxene-bearing felsic rock represents originally typical kyanite-bearing felsic granulite that was chemically modified during the interaction with the mafic lithologies.

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New exotic xenoliths found in alkali basalts in Čamovce quarry (Southern Slovakia)

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Rocks sampled by magma and erupted to the surface -called xenoliths or xenocrysts- are a very important source of information to understand better the lithosphere mineralogical composition and geological evolution. In the last years, a new type of exotic xenolith of metamorphic/metasomatic origin has been found in the Belina Hills basaltic lava flow near Čamovce, Southern Slovakia. A complete mineralogical and petrological characterization of these samples has not been provided yet, and this will be the goal of this study. The main investigative techniques have been the electron probe microanalysis (EMPA) and Scanning Electron Microscope Backscattered Electrons Imaging (SEM-BSE). A very sharp transition between the xenolith and the surrounding basalts, suggests a rapid cooling and no retrograde re-equilibration. The main mineral phases are plagioclase + pyroxene + olivine accompanied by calcite/aragonite, ilmenite, melilite, apatite, corundum and spinel. The assemblage plagioclase + pyroxene + olivine is the most common, with the pyroxenes growing mainly inside of the plagioclase. The pyroxenes revealed very peculiar compositions, yet unknown from the territory of Slovakia and unique worldwide, ranging from a diopside sensu stricto (up to 94% $CaMgSi_2O_6$), to esseneite (up to 54% $CaFe^{3+}[AlSiO_6]$) and CaTs-pyroxene, also known as kushiroite, (up to 60% $CaAl[AlSiO_6]$). The olivine + calcite/aragonite + ilmenite assemblage is rather common in some xenoliths. SEM-BSE analyses highlighted the presence of aragonite growing inside calcite, but also of ilmenite crystals touching olivine. Olivine-ilmenite thermometry yielded temperatures in the 700-880 °C range for pre-fixed pressures of 0.5-2.0 GPa. The intersection between calcite-aragonite stability boundary, calculated for a saturated CO_2 fluid, and the calculated olivine-ilmenite isopleths, provided a PT estimate range of 1.5-2.0 GPa and 750-850 °C for this assemblage. The PT estimate suggests that these skarn-line rocks were sampled at approximately 50 to 60 km in depth. The very peculiar composition of pyroxenes points to meta-stable crystallisation conditions or to crystallisation during the skarn formation. The pyroxenes were preserved to the surface because the skarn did not undergo any post-magmatic alteration. Analyses of Computer Tomography data provided information on the dimensions and on the relative orientation of the grains within the sample. Whole-rock composition analyses are fundamental for the modelling of pseudo-sections and for understanding the PT history of the xenoliths and of the crust that hosted them.

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Transition from platform to basin: mapping observations at the surroundings of the Krvavica Mountain, Sava fold region.

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The Krvavica Mountain is situated on the northern limb of the Trojane Anticline as part of the Sava folds region in Middle Slovenia. This Cenozoic fold belt is situated in the transition zone of the Alps and Dinarides, south from the Periadriatic Fault.

This area was part of the Adriatic margin of the Neotethys in the Middle-Late Triassic. During this time and later on reoccurring rifting phases created the Slovenian Basin, which continued to subside until the Late Cretaceous. The extensional phase was followed by contraction in the Paleogene and Neogene during the Dinaric and Alpine phase. This deformation placed the study area within the Alpine retro-wedge system. These major tectonic events are responsible for the complex deformation of the area. Formations in the southern part of the study area belong to the Dinaric platform whereas formations found in the northern part were formed mostly in the Slovenian Basin.

Previous mapping and cross section evaluation showed that this part of the Trojane Anticline is really complex and needs to be studied in detail. One major goal is to detect the original Triassic to Jurassic paleogeographic boundaries which are located within the strongly deformed fold belt. The goal is to understand the original paleogeographic relationships between the basin and platform developments.

We selected a study area near the Krvavica Mountain. The thorough study of the area resulted in a number of fault-slip measurements, outcrop dip data and other field observations where rock samples were taken. From these samples thin-sections will permit a preliminary understanding of the Mesozoic sequence.

Along a S to N section three formations can be traced: Triassic siliciclastic basin sediments (shale, sandstone), Triassic platform carbonates and Cretaceous carbonates. These formations are repeated at least two times by a major thrust. The thrust was associated with tilting, and probably pre-dated by early deformations, including normal faulting. The age of this south-vergent thrust is not clear. However, during the mapping we found a cemented conglomerate with limestone pebbles, which overlies strongly tilted Late Jurassic or Early Cretaceous limestones of the footwall of the thrust. The age of this conglomerate is under investigation, but it could be either Late Cretaceous or Paleogene and certainly post-date the tilting.

The two Triassic facies have an intricate relationship. Previous mapping suggested that these facies were separated by range-parallel and range-perpendicular late faults and excluded any intercalations. However, our observations clearly show that the platform and basinal formations are repeated in the dip direction. Map geometry strongly suggests that the two formations are interfingering. Carbonate bodies might be considered as prograding wedges pinching out in the dip direction. In this interpretation, the platform-basin margin is located near the Krvavica Mt., which was folded and imbricated during the Cenozoic.

A better understanding of the passive margin evolution may help our correlation with units that were displaced by the Periadriatic–Balaton Fault System. These data are necessary to the construction of a detailed N-S cross section through the junction of the Southern Alps and Dinarides and to correlate the evolution of the units that were displaced by the Periadriatic Line.

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The easternmost part of the Silvretta-Seckau Nappe System (Austroalpine Unit, Styria/Austria) and its relation to the Central Western Carpathian Unit

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This contribution reports new geochronological data from the Troiseck-Floning, forming the northeastern most extension of the Silvretta-Seckau Nappe System. The data include zircon crystallization ages determined by Laser Ablation ICP-MS as well as Rb-Sr biotite ages reflecting cooling below c. 300°C.

The Troiseck-Floning Nappe consists of a basement formed by the Troiseck Complex and a Permo-Triassic cover sequence. Paragneiss is the dominant lithology but there are several intercalations of micaschist, amphibolite, and different types of orthogneiss including pegmatite gneiss. The basement rocks experienced a Variscan (Late Devonian) tectonothermal overprint at amphibolite facies conditions. The cover sequence includes Permian clastic sediments and metavolcanic rocks, Early Triassic quartzite (Semmering Quartzite) and rauhwacke as well as Middle Triassic calcitic marble and dolomite. The Troiseck-Floning Nappe formed during the Eoalpine (Cretaceous) tectonothermal event. Eoalpine deformation at lower greenschist facies conditions is penetrative in the cover sequence, while in the basement the Variscan structures are mostly well preserved.

Detrital zircon grains from a paragneiss yielded ages in the range of 530-590 Ma, indicating a Late Neoproterozoic to earliest Cambrian source and a Cambrian to Early Devonian deposition age of the paragneiss protolith. The amphibolite bodies derived from basalt with a calc-alkaline to island arc tholeiitic signature.

Leucokratic orthogneiss with K-feldspar porphyroclasts up to 1 cm in size and a calc-alkaline granitic composition plots in the field of volcanic arc granite. According to the youngest zircon grains, it crystallized during the Variscan event in the Late Devonian. Inherited zircon cores yield mostly Cambrian to Middle Ordovician ages. Two pegmatite gneisses with a calc-alkaline composition are early Mississippian in age. Their zircon grains are characterized by high U contents (147-2400 ppm) and high U/Th ratios (60-820).

Mylonitic orthogneiss with a pronounced stretching lineation appears as layers with an irregular shape in the southern, tectonically lower part of the nappe. It is leucocratic, very fine grained and contains scattered feldspar porphyroclasts with a round shape and a diameter of about 1 mm. Its chemical composition is granitic/rhyolitic with an alkali-calcic signature. In classification diagrams it plots in the field of syn-collision granite. Zircon ages indicate a Permian age of about 270 Ma. Inherited grains yield Pennsylvanian ages reflecting a late Variscan event in the source rocks, whereas some Neoproterozoic to Ordovician grains are absorbed from the surrounding paragneiss.

Similar rocks appear on top of the Troiseck-Floning Nappe and in the neighbouring Rosskogel Nappe of the Lower Austroalpine Unit. They are identified as Permian rhyolitic metavolcanics and they share a similar chemical composition and a crystallization age of about 270 Ma. Neoproterozoic to Ordovician grains dominates their detrital zircon spectra, but there is also an age group of about 2 Ga.

Associated with the rhyolitic rocks intermediate metavolcanics (referred in the literature as "biotite-uralite schists") occur. They developed from calc-alkaline basaltic andesite and their zircon age is the same as for the rhyolitic rocks. Further, they contain a few grains with Late Variscan Pennsylvanian ages.

New Rb-Sr biotite ages in combination with literature data indicate a cooling trend within the Troiseck-Floning Nappe. A single age from the western part is 88 Ma, about 80 Ma were measured in the central part and new data from the eastern part are 75 Ma. A similar trend is documented by Oligocene and Miocene apatite fission track data from the literature.

In summary, the basement rocks of the Troiseck Complex developed from clastic metasediments and basic volcanic rocks deposited in Cambrian to Early Devonian times. During the Late Devonian, they were affected by an early phase of the Variscan collisional event, causing deformation at amphibolite facies conditions and intrusion of calc-alkaline granites. Geochemical signatures suggest a volcanic arc setting. During the early Mississippian pegmatite dikes intruded, maybe during decompression and exhumation. At least in Permian time the Troiseck Complex was at the surface, because clastic sediments and volcanic rocks were deposited on top. Permian volcanic and subvolcanic rocks include rhyolite and basaltic andesite. Even if the rhyolite is characterized by a syn-collisional signature, an extensional environment can be assumed based on regional considerations. In Triassic times carbonate platform sediments were deposited. During the Eo-Alpine collision the unit was part of the tectonic lower plate and subducted to shallow crustal levels, indicated by a lower greenschist facies metamorphic overprint. The Troiseck-Floning Nappe was formed and exhumed since about 85 Ma. Rb-Sr as well as apatite fission track data indicate a tilting with more pronounced exhumation and erosion in the eastern part during Miocene lateral extrusion of the Eastern Alps.

The western continuation of the Troiseck-Floning Nappe, represented by the Seckau Nappe shows an analog geodynamic history. A similar type of pre-Alpine basement is present in theTatric and Veporic units of the Central Western Carpathians. However, their Alpine tectonic evolution is different.

„Drawer structures" in landslides due to structural control on slope deformation

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Structural studies on Carpathian landslides based on field work and analysis of a high-resolution terrain model from LiDAR data, made it possible to distinguish a specific type of landslides, whose geometry and kinematics are controlled by systems of tectonic discontinuities in bedrock. The term "drawer structures" refers to deformation features on mountain slopes that are characterized by straight traces of landslide main and side scarps on geological maps. The strike of such scarps conforms to the orientation of tectonic discontinuities (joints or faults) in the bedrock.

In the studied cases, the drawer structures are most often limited by the longitudinal L and transverse T joint sets (which together define an orthogonal joint system), imposing a box-type geometry on the displaced portion of a slope. In the morphology of a slope, the detachment surface or zone crops out along the scarps and is often marked by an open tension fissure. The displacement kinematics in the detachment zone is that of a normal fault, but along the lateral (side) scarps, strike-slip faulting predominates. In a cross-section view, the gravity-driven transport of the detached landslide mass occurs along bedding planes of the landslide footwall. Three basic types of slip planes were identified:

A – single, limited to the one sliding surface
B – multiple with several discrete sliding surfaces
C – multiple with a ramp connection between sliding surfaces

The drawer structures are characteristic of landslides in thick-bedded rocks which maintain relative coherence of landslide bodies. They are often observed on bedding-parallel slopes and therefore they typically occur on backslopes of homoclinal ridges (in case of the study area: at backlimbs of major overturned folds). A special type of the drawer structures develops along the strike of layers in the bedrock which results in a wedge-shaped geometry of landslide bodies. The drawer structures can be an independent form or be a part of larger landslide.

Depending on the "drawer" location within the slope before and after the displacement, "sliding the drawer out" can result in various deformation patterns:

Case A – occurs when a single "drawer" covers the entire slope or its lower part and it advances without compression exerted from behind (free extension).

Case B – occurs when a drawer structure develops in the upper part of a slope and the sliding process causes a compression of landslide mass located at the rear on those in the lower part of slope. The results of this process can be:

1. formation of a transverse ridge
2. folding and thrusting within the sliding rock package
3. changing the type of motion from translational in the upper, to rotational sliding in the lower part of the slope

In general, the above-described structures resulted from post-orogenic extension of the External (Flysch) Carpathians, which scenario facilitated the development of landslides in. Similar structures are likely to be recognized in other mountain belts. The close dependence of their development on structural factors offers an opportunity for undertaking studies on structural geometries of landslide bedrock and enables an understanding of the processes of slope deformations. Additionally, in the proximity of landslide scarps, one can expect to find geologically interesting bedrock outcrops.

Whole rock geochemistry and zircon geochronology of meta-volcanic rocks from the Staré Město Belt, the Sudetes

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The Staré Město Belt (SMB) is a Variscan, NNW-trending tectonic zone that separates the Velké Vrbno Dome in the east (NW Brunovistulia) from the Orlica-Śnieżnik Dome in the west (SE Saxothuringia). The SMB is predominantly built of felsic and mafic metavolcanic rocks with Cambro-Ordovician protolith ages. New whole-rock geochemical studies and U-Pb zircon dating on amphibolites (including metagabbros), leptites, serpentinites and gabbros occurring in this belt have been undertaken to better understand the pre-Variscan evolution of the SMB.

Our research, complementary to earlier geochemical and geochronological investigations, indicates that the bimodal association in the Staré Město Belt is expressed by alternating layers of fine-grained amphibolites composed of Amp, Pl and Px and fine- and medium-grained leptites composed of Pl, Kfs, Qz, Grt, Bt and Ms. Such close relationships between felsic and mafic meta-volcanic rocks suggest their common origin. Our geochronological data acquired from first two zircon samples (felsic metavolcanites) confronted with geological occurrences of mafic and felsic metavolcanites confirm Late Cambrian age (ca. 496-499 Ma) of the whole bimodal association.

On the other hand, whole-rock geochemistry data suggest a significant diversity both in the chemical composition and tectonic environments of formation of the igneous protoliths. Our study confirms a geochemical diversity of the amphibolites of the SMB. Magmatic precursors of the amphibolites were tholeiitic and calc-alkaline basalts, andesitic basalts and andesites. Tectonic discrimination diagrams indicate that they were derived either from MORB, BABB, volcanic arc or within-plate magmas. On the other hand, leptites of the SMB mainly originated from rhyolites and dacites. These rocks represent magnesian to ferroan peraluminous magmas and belong to calc and calc-alkaline series. Geotectonic diagrams suggest that the felsic magmas of the SMB leptites were formed most likely in island arc or continental arc environments.

These preliminary results indicated the need of studies involving specific isotopic compositions of whole-rock and zircon for better understanding magmatic processes in the coexisting metafelsic and metamafic rocks of the Stare Město Belt.

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Detrital zircon U–Pb ages and Hf isotopic record in the Precambrian metasedimentary sequences of the Brunovistulicum: constraints on pre-collisional crustal evolution

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Although the Bohemian Massif is an extensively studied part of the European Variscan Belt, the pre-orogenic relationships of the main crustal domains, their primary palaeogeographic position and the existence of sutures between them have long been controversial. The Brunovistulicum represents the most ancient continental segment of the Bohemian Massif, only little affected by the Variscan collision. In this study, we present the zircon U–Pb ages and Hf isotopic data from the Precambrian metasedimentary successions of the Brunovistulicum. These data are correlated with published data from potential source areas and other parts of the Bohemian Massif.

The studied units (Tonian host-rocks of the Brno Massif representing Pre-Cadomian sequences and Ediacaran samples of Cadomian synorogenic successions) show contrasting detrital zircon ages and Hf isotopic patterns. Detrital zircon age spectra of two Tonian samples show a broad Palaeoproterozoic to Neoproterozoic population (c. 2.1–0.9 Ga) and a minor cluster of Archean ages, all with mostly positive $\varepsilon_{Hf(t)}$ values (– 4 to + 16). The weighted mean age of the youngest age groups yielded ages at c. 912 and 949 Ma, defining the maximum depositional ages. In contrast, seven samples from the Ediacaran sequences uniformly show a prominent Neoproterozoic age peak at c. 600 Ma with a wide range of $\varepsilon_{Hf(t)}$ values (– 15 to + 13), and only rare Palaeo- and Mesoproterozoic ages with generally positive $\varepsilon_{Hf(t)}$ values (up to + 18). The maximum depositional ages, determined by concordia ages of the youngest zircons, range from c. 604 to 556 Ma. Zircon morphology and cumulative distributions of the time intervals between the crystallization and depositional ages suggest a long sedimentary transport and collisional depositional setting for the Tonian sequences, and short transport and active-margin sedimentary environment for the Ediacaran sequences.

The age spectra of Tonian sequences are interpreted as detritus derived from the basement of either Baltica or Amazonia. The zircon Hf data indicate a juvenile nature of their magma sources with minor older crustal component. In contrast, the Ediacaran sequences were predominantly sourced from the adjacent Neoproterozoic magmatic arc with very limited input of recycled cratonic detritus. The large spread of $\varepsilon_{Hf(t)}$ values of dominant Neoproterozoic zircons suggests significant mixing of mantle-derived magmas with mature crustal material, typical of large continental magmatic arc systems. Age populations of the Ediacaran sequences of the Brunovistulicum, characterized by the lack of the Mesoproterozoic zircons, are nearly identical to those published from the Teplá–Barrandian Unit and, pointing to their similar sources during the Neoproterozoic. We consider such age populations as a record of sources actually exposed at the time of deposition, rather than the real provenance patterns.

The change in detrital zircon U–Pb age and Hf record of the Brunovistulicum, that took place between the early and late Neoproteorozoic, probably reflects the Neoproterozoic plate-tectonic reconfiguration from the Rodinia formation to the evolution of the Gondwana active margin. Our data revealed similarities challenging the main arguments for an existence of the Rheic oceanic suture between the Brunovistulicum and Moldanubicum and allow for an alternative pre-collisional model of the Bohemian Massif as a single Neoproterozoic crustal domain.

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Post-Eocene backthrusting in marginal units of the Central Western Carpathians: a new stratigraphic data from inverted thrust sheets

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Backthrust stacking of the frontal part of the Central Western Carpathian units has been found in the Kriváňska Fatra Mts and the Strážovské vrchy Mts. Backthrusts were recognized as internal nappe duplexes or south-verging displacement of Fatric-Hronic nappes, which somewhere affected the Paleogene sediments, as well (e.g. Súľov Conglomerates). Therefore, the backthrusting is considered as being connected with Early Miocene phase of transpressional deformation of the Periklippen zone.

A new zone of backthusting has been located in northern part of the Veľká Fatra Mts, and that in several drills throughout the Korbeľka structure. Moreover, these thrust sheets of the Krížna Unit are tectonically superposed on the Paleogene sediments providing a good possibility for study of their stratigraphic and structural discordance. Paleogene sediments overlap Middle Triassic dolomites of the Choč nappe by basal carbonate breccias, which pass to pelagic sequence of grey marlstones, occasionally with coralgal limestones and nummulitic-rich intervals. Paleogene formations are overthrust by Lower Cretaceous shales, which markedly differ from underlying marlstones by ductile/brittle deformation, refolding, parallel-bedding shearing, veining, etc. Lower Cretaceous shales are intercalated by volcanic bodies (hyaloclastites, green limburgites), which in some drill sections directly overlain the Paleogene marlstones. Tectonic superposition is clearly proved by occurrence of Middle Eocene microfauna in underlying marlstones (*Hantkenina lehneri*, *Acarinina praetopilensis*, *Morozovella sp.*) and Lower Aptian microfauna in overlying shales (*Paraticinella rohri*, *Hedbergella trocoidea*). Their overturned position is also indicated by inverse zonality of illitization with a higher alteration of the Cretaceous shales (130 - 170°C) and lower alteration of the Paleogene marlstones (90 - 120°). The structural discordance between strongly affected overlying sequence and undeformed footwall sequence is typical for thrust faults. These data allow to interpret post-Lutetian stacking of backthrusts, it means before the Sub-Tatra group of the Central Carpathian Paleogene Basin. This is also indicated by hiatus between Lutetian and Priabonian-Oligocene sequences in northern part of the Turiec Basin (Šutovo area).

Large-scale backthusting is also documented in Middle Váh Valley area, where the Periklippen units overlap inverted thrusts of the Hričov-Žilina Zone and Paleogene sediments of the Domaniža Basin. Here, tectonic slices of the Klape unit with Albian marlstones (so-called "Spherosideritmergel") are ovethrusted on inverted sequence of Maastrichtian – Paleocene formations (Hradisko and Hričovské Podhradie fm.) and these on the Eocene red-bed claystones (Žilina Fm.). The backthrust fault systems in the marginal mountain belt imply an important role of backstop orogenic wedging of the Western Carpathians.

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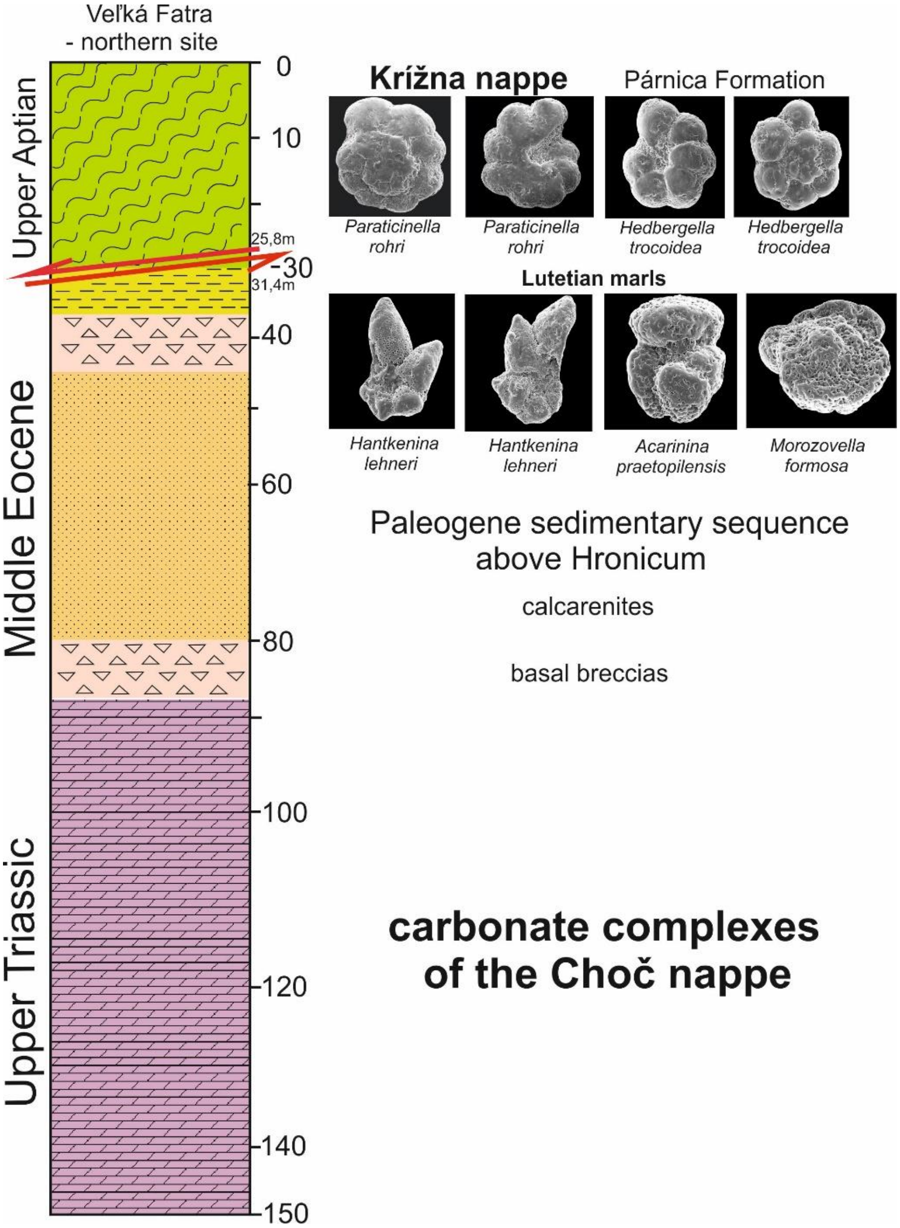

Figure 1: Krpeľany-Korbeľka section in the northern site of the Veľká Fatra Mts. proving a tectonic overthrusting of the Lower Cretaceous formations of the Krížna nappe (Párnica Fm.) on the Paleogene formation above the Choč nappe.

Paleogene basins in trans-axial zone between growing and collapsing orogenic wedge: a case of the Súľov-Domaniža and Žilina-Rajec basins (Western Carpathians)

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The Súľov-Domaniža Basin (SDB) belongs to wedge-top basins developed on the CWC orogenic wedge. Late Paleocene – Early Eocene transgression of the SDB led to development of thrust-top carbonate platforms (Kambühel Fm, Alveolina Lms) and calciclastic fans, which unconformably overlapped frontal CWC nappes and Peri-Klippen units. Synsedimentary tectonics of the SDB started in the Late Thanetian – Early Ypresian by normal faulting and disintegration of the orogenic wedge margin. The basin was supplied by continental margin deposystems, and filled with submarine landslides, fault-scarp breccias, base-of-slope aprons, cohesive debris flows and finally also diluted-flow deposits. Thick conglomerate lithosomes were accumulated from Late Thanetian to Early Lutetian. They are intercalated by claystone interbeds with rich planktonic and agglutinated microfauna, implying deep-water environments of gravity-flow deposition. The rapid subsidence was accelerated by gravitational collapse and subcrustal tectonic erosion of the CWC plate, which probably resulted from a supercritical taper of orogenic wedge due to subduction and underthrusting of the Oravic ribbon continent.

During the Late Ypresian – Lutetian, the SDB merged with adjoining Paleogene basins of the Mid-Slovakian weakness zone (MSWZ) under conditions of bathyal up to abyssal deposition. Lutetian formations are formed by hemipelagic marls and turbiditic sequences, non-calcareous red claystones with Reticulophragmium amplectens and various deep-water deposits (Domaniža Fm., Žilina Fm., Hájik Mb., etc.).

Basin deepening was enhanced by Lutetian transgression, which enabled a marine connection with the Magura Ocean. Southern basin of MSWZ in the Horná Nitra Depression is akin to the Krappfeld-type succession with basal reddish terrestrial sediments followed by Late Paleocene/Early Eocene shallow-marine formations and Lutetian deep-water marls. This implies a southward connection of MSWZ with the Carinthian embayment of the Mediterranean Tethys and northward connection with Alpine Tethys. Lutetian sea also flooded the Central-Carpathian Paleogene fore-arc basin (CCPB) by accommodation of carbonate ramps (Borové Fm.).

Since the Lutetian, deep-water basins accommodated a weakening zone (MSWZ) between north-westward growing orogenic wedge and the north-eastward moving crustal fragments of the CWC (Fig. 1). Therefore, the common feature of the MSWZ is a superposition of wedge-top and fore-arc basins like this in Žilina, Rajec, Domaniža, Pružina, Horná Nitra, and Turiec depressions (Fig. 2).

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

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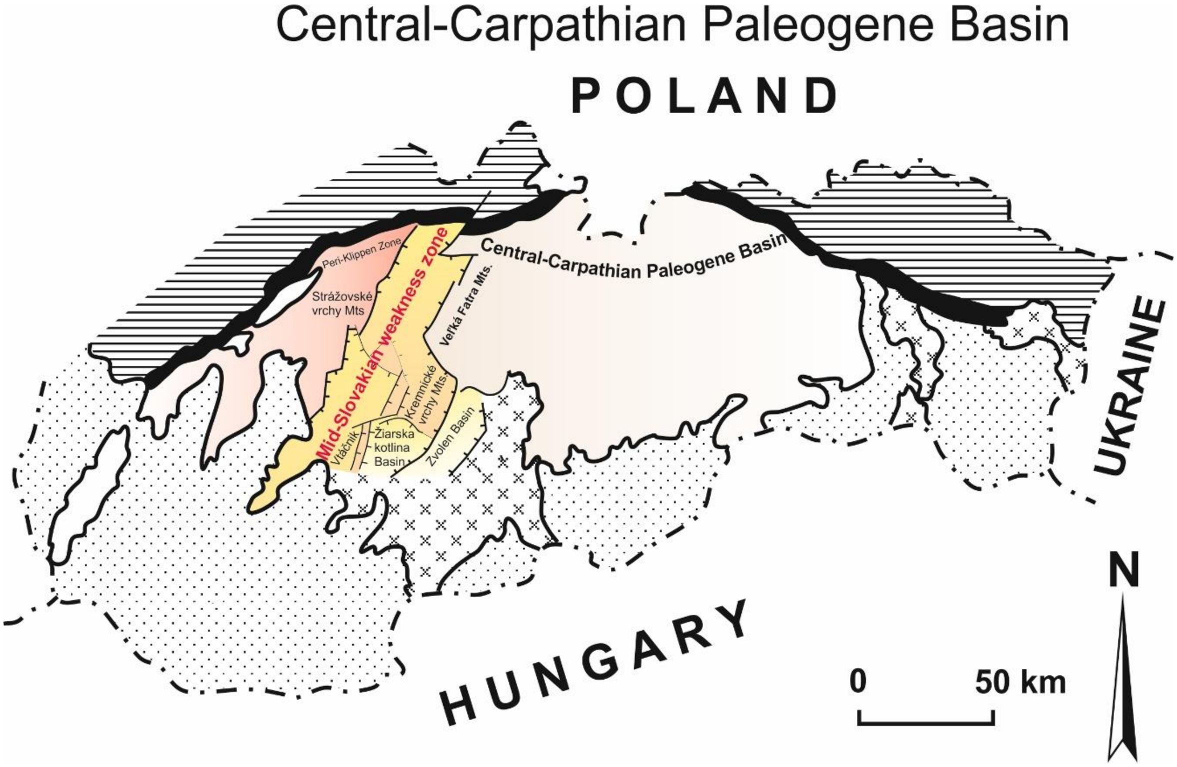

Figure 1: Mid-Slovakian weakness zone between wedge-top and fore-arc basins of the Central Western Carpathians.

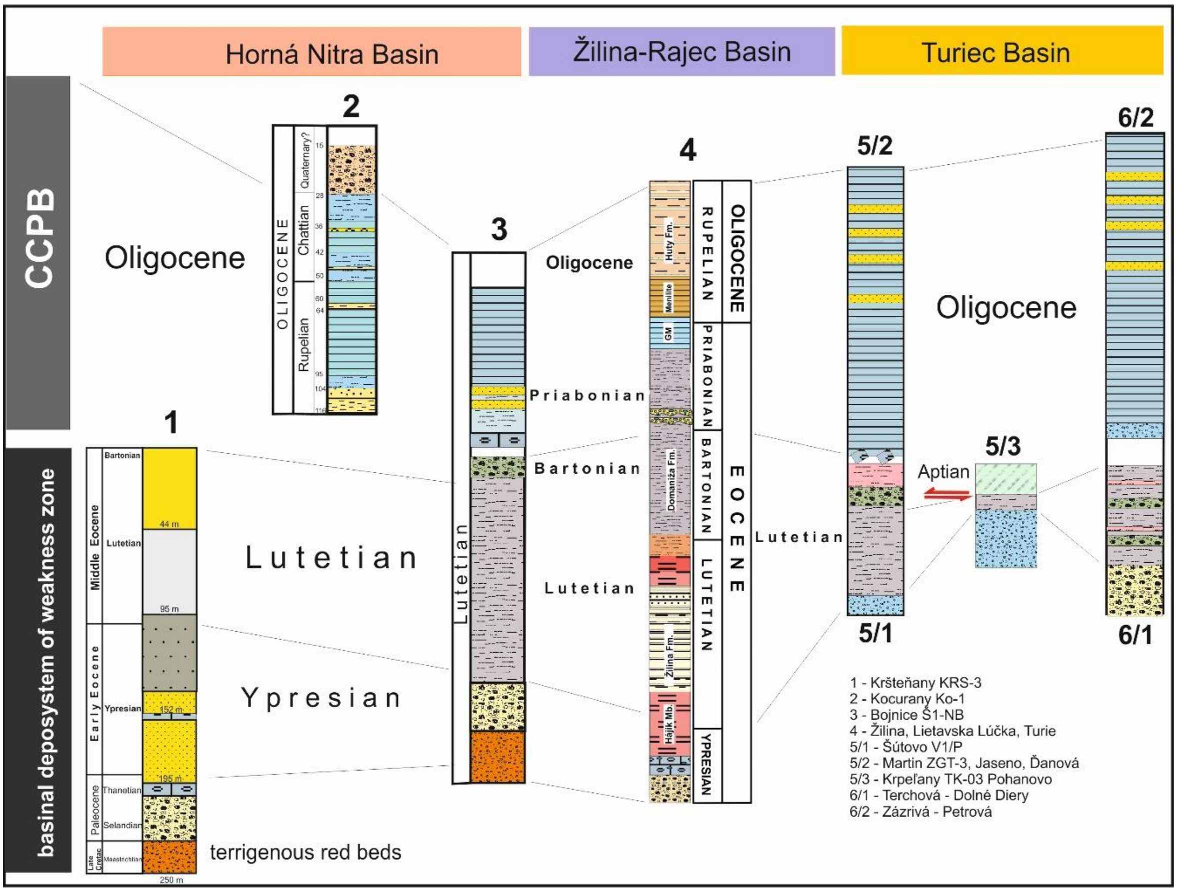

Figure 2: Correlation scheme of the Paleogene formations within the Mid-Slovakian weakness zone (Horná Nitra, Žilina-Rajec and Turiec basins).

Cretaceous alkali volcanics in the Western Carpathians – new data of age and isotope composition

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Cretaceous alkali volcanics are known from various tectonic units of the Western Carpathians (Silesian unit, Klippen belt, Tatric, Fatric and Hronic units). Their mineral and chemical compositions are similar and they typically occur in this mineral association: Ol + Cpx + Amp + Bi ± Ne ± Spl. Most minerals are zonal and have high contents of TiO_2 (Cpx, Amp, Bi). The texture and structure of the rocks depends on the shape of the bodies (dykes, effusive or intrusive bodies). With regard to their geological position, they can be locally called alkaline lamprophyres. Based on geochemical data, they have a mantle origin. On the other hand, the alkaline nature of the rocks (inclusion trace element and REE data) documents that the volcanism was connected with the short living rifting zone. The age inclusion of the volcanism is currently well defined on the basis of geochronological data: 100 to 120 Ma. The assumptions of some other authors (based on paleontological data) of the multiphase age of volcanism (younger phase of 80-90 Ma) have not been confirmed. New (Fig. 1) and older isotopic data suggest that the source of the magmas of the Cretaceous alkali volcanics from the Western Carpathians was upper mantle, similar to HIMU and BSE. $^{143}Nd/^{144}Nd$ isotope data for the study volcanites are stable, but $^{87}Sr/^{86}Sr$ ratio has a greater dispersion. Based on these data, it can be assumed that the Cretaceous alkali volcanics from the Western Carpathians have an isotope ratio ($^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$) similar to that of the Pyrenees, and/or average of alkaline lamprophyres. The similarity of the chemical and isotopic composition of Cretaceous alkali volcanites of the Western Carpathians with the Tertiary and Quaternary alkaline volcanites of Western and Central Europe suggests that the mantle reservoir from which these magmas were derived existed from the Lower Cretaceous. The age and geochemical composition of Cretaceous volcanics in the Western Carpathians and other parts of the Alpine-Carpathian belts (Northern calcareous Alps, Valais Trough and some Mesozoic alkaline rocks of Hungary); point to identical extensive tectonic conditions during the Middle Cretaceous in all parts of the Alpine-Carpathian sector Tethyd Neo-Europe. The occurrence of similar (age and geochemical) rock types in the Northern Pyrenees and other European occurences can determine the presence of a large East-West oriented rift system.

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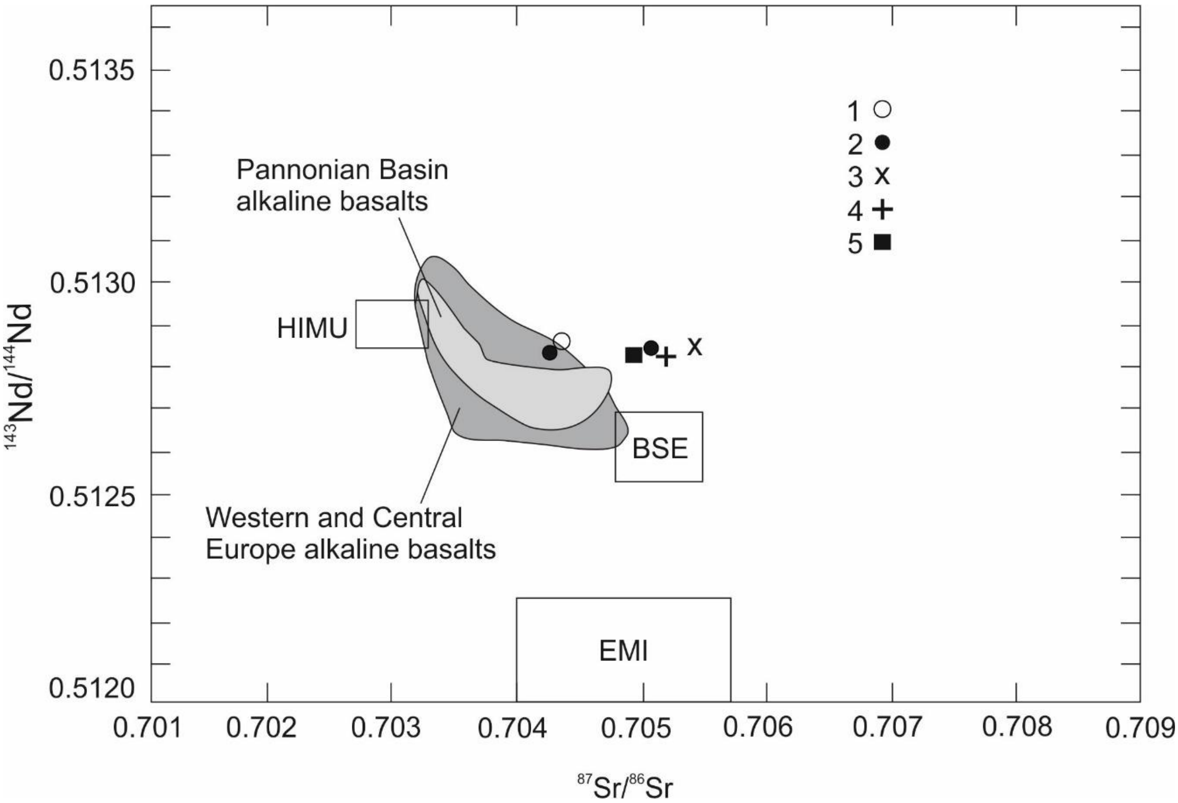

Figure 1: Sr and Nd isotope variations of Cretaceous Western Carpathians alkali basalts compared with fields of alkaline basalts from the Pannonian Basin, and from Western and Central Europe. Symbols: 1 - Višňové, 2 - Hanigovce, 3 - Čebrať, 4 - Liptovská Dúbrava, 5 - Velikiy Kamenec (Ukraina)

Finite pattern of Barrovian metamorphic zones: interplay between thermal reequilibration and post-peak deformation during continental collision—insights from the Svratka and Thaya domes (Bohemian Massif)

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The Barrovian inverted metamorphism of the Svratka Dome developed within two nappes derived from the Brunia continent that was thrust beneath the Moldanubian orogenic root. The metamorphism increases from biotite–chlorite zone in the basement to very closely spaced staurolite, kyanite and sillimanite zones at the top of the nappe pile. The sequence of mineral growth, chemical zoning of garnet and pseudosection modelling indicate prograde paths from 4.5 kbar/510 °C to 5.5 kbar/540 °C in the garnet zone, from 6 kbar/530 °C to 7 kbar/600 °C in the staurolite zone, and from 3.5 kbar/510 °C to 8.5 kbar/650 °C in the kyanite zone. The age of monazite inclusions in garnet and staurolite is interpreted to reflect prograde metamorphism at 338 ± 7 Ma and 336 ± 7 Ma, respectively. An older matrix monazite crystal is interpreted as dating prograde crystallization at 345 ± 7 Ma, whereas a younger monazite group records recrystallization at/or down to 334 ± 7 Ma. While these petrological and geochronological data are consistent with data from an inverted metamorphic sequence of the southern Thaya Dome, the spacing and distribution of metamorphic zones, nappe thicknesses, and late structures are different in the two domes. An antiformal stack of imbricated basement sheets and the extreme attenuation of metamorphic isograds at the top of the nappe pile in the Svratka Dome are explained by a relatively cold overthrusting Moldanubian domain, formed mainly of middle orogenic crust. The homogeneous thickening of the hinterland-dipping basement duplexes and the regular spacing of metamorphic isograds in the Thaya Dome are explained by a hot overriding Moldanubian domain, which in this region has a high proportion of exhumed lower orogenic crust and formed a hot mid-crustal channel.

Reconstructing the tectonic evolution of a fold-and-thrust belt: A multi-scale approach to the Silesian Nappe, Outer Carpathians, SE Poland

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The structure of fossil fold-and-thrust belts is usually the result of a complex deformation history. Thus, in order to understand its course, a multi-scale approach is required that allows the entire scenario to be captured.

We present a study of the tectonic evolution of the south-eastern part of the Silesian Nappe in Poland (Bieszczady Mountains). The analysed part of the Silesian Nappe is largely composed of Oligocene flysch strata and these are studied in this contribution. We analysed different sets of deformation bands and faults at various scales: ranging from thin-section analysis through outcrop-scale observations and measurements collected at 40 sites to the regional analysis of tectonic lineaments derived from high resolution digital terrain model (DTM) data. In order to determine a scale of vertical movements we supplemented our results with data on paleotemperatures estimated based on content of smectite in mixed layered illite-smectite.

We captured the tectonic history of the analysed part of the Silesian Nappe from the onset of the deformation – from the pre-folding shortening to the post-orogenic collapse. We found that the onset of deformation i.e. the shortening, pre-dated the regional folding. It resulted in the formation of deformation bands and the nucleation of detachment horizons which may have greatly influenced later folding. We recorded several thrust fault sets at the outcrop-scale, which post-date the regional folding and registered several shortening directions. Based on map-scale analysis of the digital terrain model, we recognised strike slip faults which largely post-date the folding. The latest structures traced include normal faults. The paleotemperature distribution does not indicate large-scale vertical movements after reaching thermal maturity.

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The Ediacaran active margin along the north-eastern Baidrag block (Bayankhongor Ophiolite Zone, western-central Mongolia)

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The Bayankhongor Ophiolite Zone (BOZ) located at the northeastern margin of the Baidrag microcontinent in the western-central Mongolia represents a key lithotectonic unit of the Mongolian orogenic collage. The BOZ has been traditionally considered as one of a largest and major ophiolitic system representing a vestige of a Neoproterozoic ocean-floor basin that developed between two ancient microcontinents named the Khangai in the northeast and Baidrag in the southwest. However, the age, petrology and tectonic setting of many magmatic complexes of the BOZ are still poorly constrained. In order to fill the gap, we carried out geochemical and isotopic characteristics as well as zircon U-Pb ages and Hf isotopic data of magmatic rocks from the Khan-Uul area in the southeastern part of the BOZ. The rock assemblage of the Khan-Uul area is composed of volcanic rocks intercalated with the carbonates and ultrabasic to felsic magmatic rocks commonly having both cumulate and mingling textures. The studied rocks were affected by the greenschist to lower amphibolite facies metamorphism. Nearly all samples including the serpentinite (Mg# = 81 – 90 mol.%), the gabbro (Mg# = 71 – 81 mol.%) and the TTG-type intermediate to felsic rocks (Mg# = 15 – 47 mol.%) reveal primitive geochemical characteristics and notable depletion in K_2O (K_2O/Na_2O = 0.01 – 1 wt.%). Based on the geochemical characteristics, they indicate a transitional composition from mainly tholeiitic to calc-alkaline. The REE and trace-element patterns show obvious enrichment in large-ion lithophile elements (including Cs, Ba, K, Sr and Pb) relative to highly depleted high-field strength elements such as Nb, Ta, Zr and Ti. In general, such a geochemical characteristic indicates a magmatic arc source and oceanic subduction environment. A whole-rock Sr-Nd isotopic data of magmatic rocks from the Khan-Uul area reveal a broad range from negative to positive initial epsilon Nd values (ε_{Nd}^{590} = -3.9 to +2.2) with relatively young Nd model ages ($T_{DM}^{Nd}{}_{.2stg}$= 1559 - 1079 Ma) pointing to a limited crustal contamination. U-Pb ages of 10 dated samples revealed that the magmatic rocks were mainly emplaced during the Ediacaran (ca. 600 – 570 Ma). In-zircon Hf isotopic analyses exhibit significantly positive epsilon Hf values for zircons of Ediacaran age ($\varepsilon_{Hf}^{(t)}$ = +3.9 to +13.8) with variable two-stage Hf model ages ranging from 1499 to 658 Ma. In contrast, samples of trondhjemite show mostly negative ($\varepsilon_{Hf}^{(t)}$ = -5.5 to -1.5) and a few positive ($\varepsilon_{Hf}^{(t)}$ = +1.3 to +6.1) epsilon Hf values with relatively older Hf model ages ranging from 2389 to 1081 Ma. Our geochemistry data indicate that the studied magmatic rocks from the Khan-Uul area originated in the relatively primitive Ediacaran magmatic arc. The whole-rock Sr-Nd and zircon Hf isotopic data further suggest the dominant contribution of the juvenile material via partial melting of the depleted mantle with only minor crustal components. This study shows that a large part of the southeastern BOZ does not belong to the ophiolite suite as it was widely accepted. Contrary to broadly assumed knowledge, the current data point to an active margin evolution of the northeastern edge of the Baidrag Block during Ediacaran.

Syn-rift, post-rift and inversion stages of the Danube Basin recorded by changing depositional systems

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Changes in geodynamic evolution stages of a basin strongly modify both sediment supply and accommodation rate, having major impact in evolution of depositional systems. Tracing these changes might be challenging, because it requires extensive datasets ranging in scales from depositional process variability, trough facies associations stacking patterns up to temporal and spatial variations of sequence properties in basin scale. The range of scales imply another need to satisfy for depositional system reconstructions, namely robust chronostratigraphic framework.

This study focuses on recently published Late Miocene to Quaternary evolution of the northern Danube Basin. Sedimentological and stratigraphic observations are based on thousands of boreholes, a number of seismic lines and outcrops, while geochronology relies mostly on cosmogenic nuclide methods: authigenic ^{10}Be/^{9}Be, ^{26}Al/^{10}Be burial dating and exposure depth profile dating.

The first discussed period ranges between ~11.6–9.5 Ma and represents the last of four rifting phases of the Danube Basin. It caused accelerated subsidence (up to 1000 m/Ma) in the Komjatice and Gabčíkovo-Győr depressions, and led to a formation of topographically differentiated bottom of Lake Pannon, comprising more than 500 m deep basin floor depocenters, submerged basement highs as well as subaerially exposed horsts. The large increase of accommodation was followed by the arrival of the paleo-Danube deltaic system, which prograded across the basin and caused normal regression of Lake Pannon from the area after ca. 8.7 Ma.

While the rifting phase caused abrupt increase of accommodation, following post-rift period between ca. 9.5 and 6.0 Ma was characteristic by smooth decrease of subsidence intensity with temporally stable values. The pace was still relatively high (400–50 m/Ma) andthe whole basin was dominated by a broad alluvial plain comprising paleo-Danube and its Western Carpathian tributaries (e.g., paleo-Váh, paleo-Hron). A relative tectonic quiescence led to a high accommodation/sediment supply ratio and high preservation of overbank muddy deposits. However, distribution of channel belts is uneven spatially and reflects spatial differences in subsidence rate.

Stable post-rift subsidence was replaced at ~6.0 Ma by the basin inversion. This process continues up to present day and includes basin scale folding with syncline located in the central part of the basin and anticlines at the Malé Karpaty Mts. and the Transdanubian Range. The folding led to differential movements and up to 340–620 m denudation on the basin margins and relatively continuous deposition in the basin centre. The fluvial depositional systems recorded a base level rise, and the largest areal extent of deposition was connected with channel mobility across the whole area of the Danube Basin at ~4.0–3.0 Ma. The following decrease of areal extent covered by fluvial deposition resulted in the formation of river terrace staircases. This evolution was probably caused by climatically triggered changes in sediment supply and by gradual exhumation of massifs with higher resistance to erosion. The high spatial variability of accommodation caused prevailing non-deposition and fluvial bevelling on the basin margins alternated with condensed deposition of only sandy and gravelly channel belts. On the other hand, central depression recorded dominant deposition of overbank facies around 5 Ma due to the base level rise, which was gradually replaced by channel belts representing paleo-Danube fluvial fan prograding from NW to SE.

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Deformations in a periglacial eolian sand sheet reveal a 26–16 ka activity of the Vienna Basin Transfer Fault

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Paleoseismological research focused on the intensity and recurrence intervals of earthquakes trough geological time is of primary importance for the prediction of geohazards related to seismic events. It is done routinely by dating the exposure of fault scarps using *in situ* produced cosmogenic nuclides, by dating the deposition of strata progressively deformed by active faults, but also by the identification of soft sediment deformation structures (SSDS) interpreted to be triggered by a seismic shock. However, most studied liquefaction SSDS can be caused by a number of triggers and interpretation is commonly ambiguous.

Here we present a study of SSDS, namely fractures and collapse wedges (Fig. 1), which are rarely documented in publications, and associated further deformations. They were observed in an eolian sand sheet exposed in the Bažantnica sandpit near the town Plavecký Štvrtok, in the eastern Vienna Basin. The several dm wide collapse wedges are sharply delimited from the surrounding sand and are filled by blocks/slices of the surrounding succession. The most common features, simple fractures have dip angles of 45° to 85° degrees and along them sand layers are commonly bent down. All wedges exhibit obvious signs of downward movement of material. The two sides of either collapse wedges or fractures show no or in a single case very small vertical offset. Both wedges and fractures are planar, without significant variation in orientation. Wedges and fractures are grouped in horizons and are topped by an erosional surface. The fractures are oriented systematically in N-S to NE-SW direction. The horizons crosscut by wedges commonly include layers with a chaotic structure, created through the disruption of the original sediment into cm- to mm-sized fragments. Less frequently folded layers also occur, with series of cm- to dm-amplitude folds. Fold shapes vary from symmetrical to asymmetrical and from upright to overturned.

Luminescence dating revealed that the deformed sand sheet accumulated during the MIS2, partly during the Last Glacial Maximum. The published paleoclimatic studies imply a discontinuous permafrost or seasonal frost for the region with mean annual precipitation of 300–490 mm. The described conditions imply that the sand sheet strata could have behaved cohesively to some degree because of frozen capillary water, what may have allowed strongly inclined fractures to form without the collapse of the sand above the crack. The locality lies just along the boundary fault of the Zohor-Plavecký Basin, a graben along the Vienna Basin Transfer Fault System, which experienced significant subsidence during the Quaternary. The systematic orientation of the brittle deformations and their position relative to the paleotopography excludes slope failure and cryoturbation as formative processes. The described characteristics indicate seismic shock as a potential cause of forming the cracks on the surface. The distribution of the deformed horizons within the dated succession implies a tentative estimate of earthquake recurrence interval in the order of ~500 years per event. The lack of sand injections indicates earthquake magnitudes below 5.

Acknowledgement: The study was supported financially by the Slovak Research and Development Agency (APVV) under contracts Nos. SK-HU-2013-0020, APVV-16-0121 and APVV-20-0120 and a CEEPUS grant (for KS). Katarína Lacová (Military Forests and Estates of the SR, SOE), Peter Hiadlovský (Ministry of Defense SR, Office of Process Management, Organization and Specialized State Administration), Ján Karovič (SAZAN, ltd.) and the Military district of Záhorie (Malacky) are thanked for kind allowance to perform the research in the Bažantnica sandpit. Thanks to Ágnes Novothny (Eötvös Loránd University, Budapest) for the help in OSL measurements, to the colleagues in the Mining and Geological Survey of Hungary: Attila Nagy for gamma spectrometry measurements, Miklósné Bátori and Judit Füri for sample preparation, and Zsolt Horváth for water content determination.

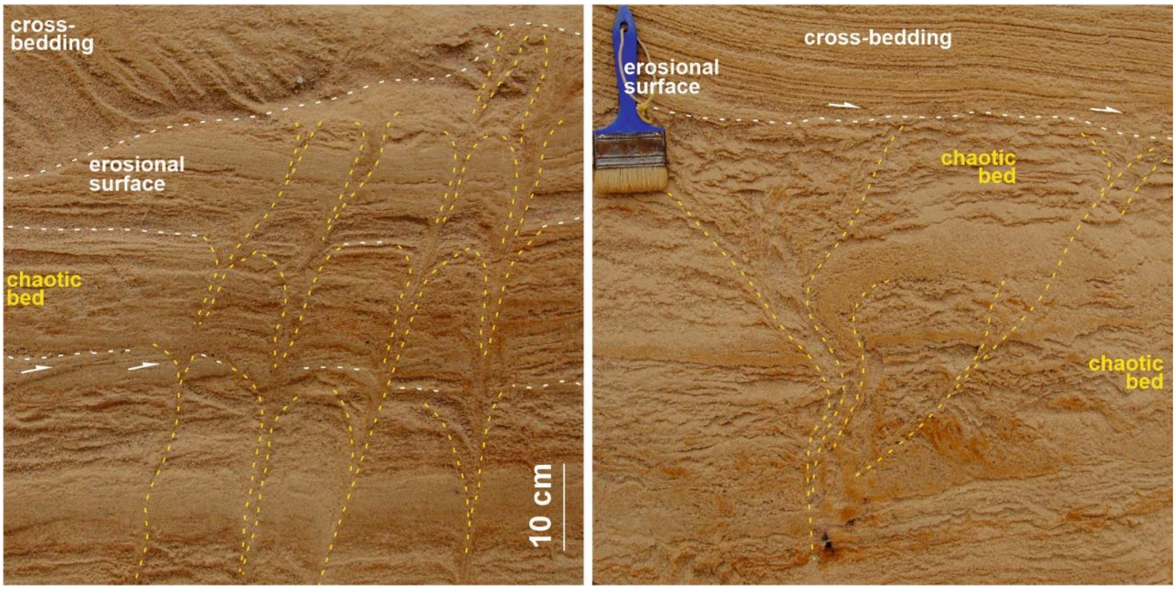

Figure 1: Examples of collapse sand wedges.

Revealing the invisible: creating an accurate 3D interpretation of the rock internal structure in deep mine environment by means of geological, geotechnical and geophysical methods

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In the rock environment of former uranium mine Rožná, located in the southeast of the Czech Republic in crystalline rocks of the Bohemian Massif, which is now in the phase of closure, various experiments were conducted during the research project "Data acquisition from the deep horizons of the Rožná mine". Aim of these experiments was to assess and describe spatial distribution of geological, geotechnical and transport properties of rock massif and to evaluate the influence of large tectonic zone as a safety measure for future deep geological repository of radioactive waste.

A large, accessible block containing a major fault zone of approximately 20 m in thickness was selected at mine level 20 (1 km below ground). This block has been thoroughly investigated by all available methods. That contained detailed structural mapping of the adjacent galleries using 3D photogrammetric models of the gallery walls, seismic survey in horizontal and vertical profiles, in-situ geotechnical survey in both, foot-wall and hanging-wall of the main fault zone, and laboratory experiments assessing rock mass characteristics.

The aim was to visualise and better understand the internal characteristics of rock mass and the fault zone influence on rock properties with implications for defining safety envelope around critical geological features. This was performed by evaluating intensity of fracture distribution with increasing distance from the tectonic zone, the extent of the excavation damaged/disturbed zones in combination with local petrophysical properties and major fractures identified by the seismic survey. All the data transferred into the 3D environment, in a form of interpreted cross-sections, spatially distributed data and interpolated or calculated surfaces, created a comprehensive 3D model of the studied rock massif.

Acknowledgement: The study was supported by SURAO project "Data acquisition from the deep horizons of the Rožná mine".

Deposition and paleogeography of the deep-sea flysch Magura Basin (Western Carpathians)

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The Western Carpathians are part of the Alpine-Himalayan orogenic belt. Regionally the Western Carpathians can be divided into the Central Western Carpathians and the Outer Western Carpathians (synonym "flysch belt"). The Outer Western Carpathians are mostly formed by deep-sea "flysch" deposits (typically alternating sandstones and shales) mostly of the Upper Cretaceous and Paleogene age and they contain an extensive record of paleogeography of several basins and source areas. The basins fill was finally intensively folded and thrusted. The deposition environment of the Outer Western Carpathian represented facies of the internal troughs (Magura and Fore-Magura/Dukla Basins) and external basins (Pouzdřany-Ždánice-Waschberg, Silesian, Sub-Silesian and Skole Basins). The Magura Nappe is the largest tectonic unit of the Outer Western Carpathians. Nappe consists of five tectono-lithofacies units – Biele Karpaty, Krynica, Bystrica, Rača and Siary Units.

The Magura Basin was not isolated basin, but it was interconnected with neighbouring basins (Rhenodanubian and Dukla Basins). The Magura Basin was a NE prolongation of the Piemont-Liguria Ocean connected with the Valais Ocean through Rhenodanubian Basin. Deposition of the red mudstones points to the connection of the Magura Basin with the Atlantic Ocean through the Ligurian Ocean and with the Neotethys through the Ceahlau-Severin Ocean.

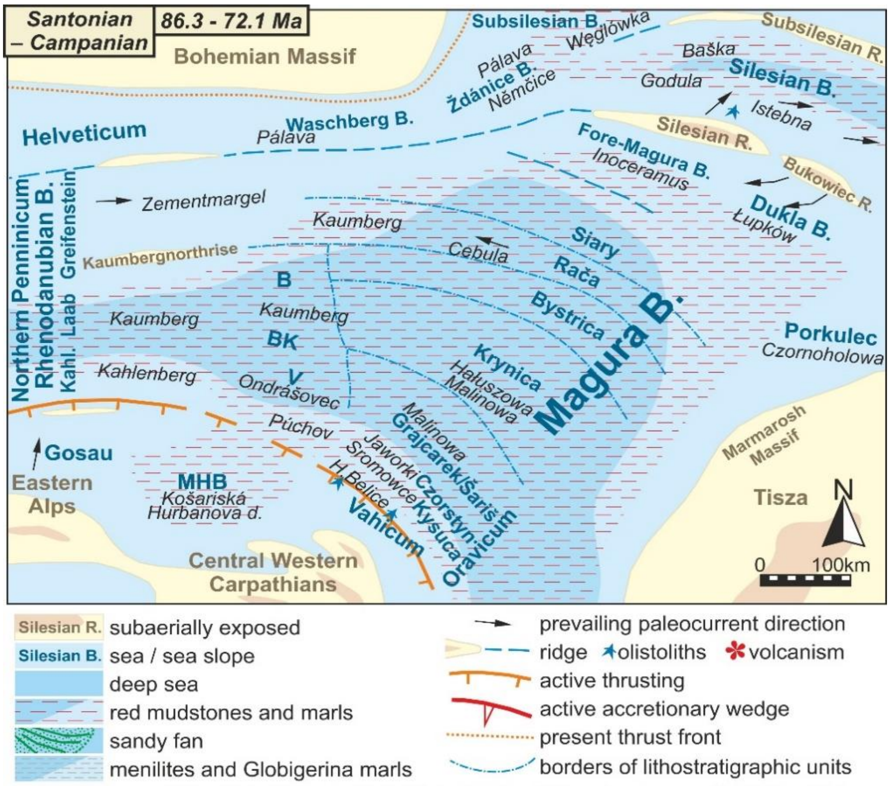
The basement of the Magura Basin as well as the source areas do not protrude on the current surface. The basin, as an SW part of the Western Carpathian flysch basins realm, was opened by syn-rift extension during the Upper (Middle?) Jurassic to Lower Cretaceous according to the rudimentary preserved oldest deposits in the Morava and in Slovakia/Poland (Šariš/Grajcarek Unit). The time, when the basin started to open, has not yet been reliably confirmed, because the nappe has completely detached from its substratum along the ductile Upper Cretaceous to Paleocene clayey formations. Sedimentary fill of Magura Basin was preserved as the root-less nappes. Sedimentation took place on an attenuated continental and/or oceanic crust of the Northern Penninic realm and on the passive margin of the Northern European Platform and/or Bohemian Massif. Even the oldest preserved sediments of the Magura Basin have the character of deep-sea sedimentation. Upper Jurassic to Lower Cretaceous carbonates, marls and "flyschlike" deposits form Kurovice tectonic klippen and Cetechovice and Lukoveček olistoliths. The deposits of the Outer Western Carpathian units are mostly composed of synorogenic flysch deposited in the deep-marine environment. These deposits are represented by a variety of gravity-driven currents (turbidites, debris flows and olistoliths). The sedimentation took place in diverse depositional environments from the steep slopes of the ridges to the deep-water environment in the central part of the basin. Prevailing monotonous hemipelagic and thin-bedded flysch sedimentation was disrupted by several depositional fans penetrating hundreds of kilometres deep into the basin. Several sandstone deep-sea fans could be defined based on detailed facial and petrographic research and paleocurrent measurements.

Basin was bordered by continental crust ridges (cordilleras) which delivered a clastic material to the basins. The geological structure of the source areas can be interpreted only from the detritic material, pebbles and rare olistolithes. Paleocurrent directions and the increasing proximity of clastic facies focus the localization of the source areas. Three types of the source areas can be distinguished in the Magura Basin – the northern sources (passive margin), the intrabasinal sources (thrust belts) and the southern source (active accretionary wedge).

Gravity currents from the northern sources (Hostýn, Fore-Magura and Silesian Ridges) deposited wide wedge (Soláň and Mutne type sandstones) or smaller fans (Riečky, Skawce, and Mrázovce type sandstones) along the northern passive margin of Magura Basin. The Silesian Basin, as a NE part of the Western Carpathian flysch basins, was individualized during the Lower Cretaceous by the Silesian Ridge uplift as a thrust belt with mountain topography. Hostýn Ridge is understood as a separate western continuation of the Fore-Magura Ridge. The Hostýn, Silesian and Fore-Magura Ridges were exposed by the compression and they contain, except Variscan crust similar to the Bohemian Massif, incorporated element of Cadomian (Pan-African) crust similar to Brunovistulian, Malopolska and Dobrogea terranes and Moesia platform. Based on heavy minerals analysis assumes a different structure of source area for sandstones of Mrázovce and Makovica Mbs. in contrast to the sandstones from the western part of Magura Basin.

Intrabasinal sources (Szczawina and Southern-Magura Ridges) supplied the detritic material to the Szczawina, Piwniczna, Zábava, Kýčera, Poprad, in part Ropianka and other lithostratigraphic units. Shortly active Szczawina Ridge arises in the center of the basin during the Maastrichtian and Paleocene (Szczawina type sandstone).

The southern source is represented by the prograding Western Carpathian accretionary wedge (Western Carpathian thrust belt or Neopieninic Exotic Ridge) extended along the southern margin of the Magura Basin. At the end of the Cretaceous, Czorstyn Ridge, a continental ribbon, was incorporated to the wedge. The accretionary wedge was defined in Eastern Slovakia as Neopieninic Exotic Ridge, uplifted during the Paleocene to early Eocene. The wedge was characterized by its prograding, which culminated during the late Eocene and Oligocene. The wedge was tectonically complicated thrust belt built of the different Pieniny Klippen Belt units (Sub-Pieniny, Pieniny, Klape, Fatric). The wedge supplied high amount of the quartzite and carbonate clastic material (up to pebbles and olistoliths) into the basin (Javorina, Drietomica, Chabová Mbs., Jarmuta and Proč Fms.) also recycled from the Veporic-Gemeric-Meliatic-Silicic collisional orogenic belt. The wedge gradually consumed the Magura Basin from the south. Southern source formed several smaller fans/wedge and supplied the basin with particularly quartz-carbonate sand for e.g. Jarmuta, Proč, Javorina, Svodnica and Chabová Fms.



abbreviations: *BK – Biele Karpaty Unit (B/V – Bošáca/Vlára development), MHB – Myjava--Hričov Basin, PKB – Pieniny Klippen Belt, CCPB – Central Carpathian Paleogene Basin*

Figure 1: Palinspastic map displays the Magura Basin and adjacent areas during the Santonian to Campanian. Red marls and mudstones deposition overlapped most of the basin. The supply of sedimentary material was limited. Active thrusting took place in the Central Western Carpathians.

Only the huge fans of Magura and glauconitic sandstones penetrated deep into the basin. Afore-mentioned fans and lobes penetrated into the more or less stable and smooth plain environment with thin-bedded and/or variegated mudstones sedimentation.

The deposits of basin-fill were gradually (from the south) scraped off their basement and stacked in fold-and-thrust system of the accretionary wedge during the Paleogene to early Miocene subduction. The subduction of an active southern margin caused the progressing reduction and disintegration of sedimentation space. Deposition culminated in the basin during the late Eocene to (?) early Miocene (Malcov Fm.). The Malcov Fm. was deposited in smaller limited sub-basins parallel with the shortening of basin from Priabonian to Rupelian. The period was influenced by the increase of compression. The Magura Basin got the character of residual piggy-back basins above the Outer Western Carpathian accretionary wedge. Initiation of massive subduction of the southern edge of the Magura Basin floor migrated from the west (Biele Karpaty Unit – Lutetian) to the east (Bartonian and Priabonian). The vanishing Magura subduction was accompanied by continuous growth of the fold-and-thrust system with maximum shortening during the Oligocene. Most of these youngest deposits were later removed by erosion.

The Magura Nappe forms a fold and thrust system. The nappe was thrusted over the Silesian Nappe and together with other more external units of the Outer Carpathians was thrusted over the inclined ramp of the Northern European Platform. Moreover, the Krynica Unit was as well backthrusted to the south over the Pieniny Klippen Belt. Thus, the Outer Western Carpathians form a huge wedge-like body with large nappes folded-slices.

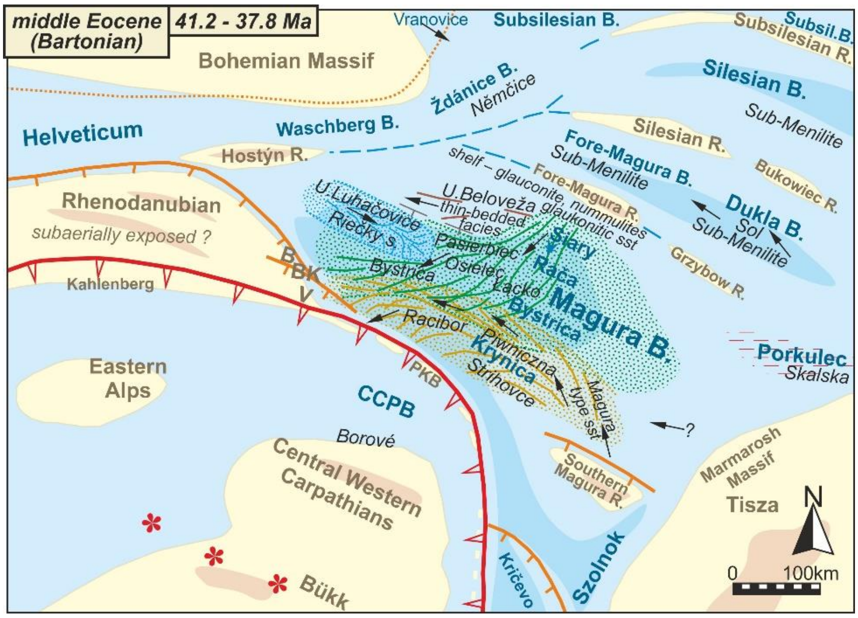


Figure 2: Palinspastic map displays the Magura Basin and adjacent areas during the middle to late Eocene. Intensive clastic sedimentation was typical for most Magura Basin.

Low thermal constraints on the Alpine evolution of the Gemer Belt (Western Carpathians)

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The Western Carpathians represent the northernmost part of the Alpine orogen in Central Europe. The research was focussed to study the late stages of the Carpathian orogen evolution covering mainly its internal parts. Zircon and apatite fission track (ZFT and AFT) thermochronology has been used in order to derive quantitative constraints on the low-thermal evolution of basement and sedimentary rocks in the Gemer Belt. In the Gemer Unit, the Alpine metamorphic peak is considered to be Early Cretaceous (~140–115 Ma) and is related to Cretaceous N–S convergence in the Inner Western Carpathians (IWC) orogenic wedge. After the metamorphic peak, which was caused by the Alpine nappe stacking, a tectonic collapse is evidenced by cooling of the Gemeric Unit and the overlying Meliata subduction-accretionary complex.

Basement samples from the Gemeric Unit of the IWC yielded cooling ZFT ages in the range from 108.2 ± 7.0 to 73.0 ± 4.5 Ma and apparent AFT ages between 62.5 ± 7.3 and 59.3 ± 6.1 Ma. The Upper Permian to Lower Triassic siliciclastic sediments of the Stratená Nappe, belonging to the Silica Unit, yielded cooling ZFT ages from 121.1 ± 21.9 to 72.5 ± 14.7 Ma apparent AFT ages between 72.8 ± 8.0 and 61.3 ± 7.3 Ma. The same siliciclastic rocks of the Vernár Nappe provided ZFT ages at 115.3 ± 20.1 and AFT ages 66.8 ± 10.5 Ma, respectively. Both nappes were heated to a temperature approximately 300°C or slightly more during the Alpine metamorphism. In any case, our data support the hypothesis that the Silica-related nappes system was at least partly incorporated into the Mesozoic accretionary wedge and contradict the widely accepted assumption that this nappe system lacks an Alpine metamorphic overprint. However, the Muráň Nappe gave ZFT ages from 259.4 ± 20.9 – 253.1 ± 18.4 Ma, which reflects the cooling of source rocks of the Lower Triassic siliciclastic deposits without any Alpine thermal overprint. The samples from the Muráň Nappe yielded Alpine cooling AFT ages between 107.8 ± 20.3 and 92.7 ± 9.3 Ma. According to ZFT and AFT data, the Gemeric Unit, an uppermost thick-skinned thrust sheet, cooled from depth levels of ~10 up to 6.0 km (temperature interval of ~300–200°C) about 108–73 Ma ago. This cooling began immediately after the collapse of overlying Meliata-Turňa Mesozoic accretionary prism with the cooling ages of the Silica-related nappes approximately (121 – 72 Ma).

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Palaeostress analysis, structural pattern and tectonic evolution of the Muráň fault (Western Carpathians)

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The Muráň fault is probably the most distinctive steeply dipping brittle structure in the Western Carpathians. Analysis of brittle deformation has been used to gain the succession of tectonic evolution of the Muráň fault by palaeostress tensors. Movement on this fault is depended on a spatial orientation of the principal palaeostress axes representing the palaeostress fields. The kinematic analysis of fault-slip data confirmed predominant strike-slip nature of the fault during the whole history sometimes disrupted by quiescence periods or normal faulting. The Muráň fault can be as old as 85 Ma and originated as ductile shear zone. During the latest Cretaceous to earliest Paleocene, the Muráň fault can be considered to be the sinistral transpressional strike-slip fault. During this time period, with given orientation of the palaeostress field, the fault originated as a ductile and later followed as a semi-ductile to brittle shear zone. A significant reorganization of the palaeostress field was carried out approximately at the boundary of the Paleocene and Eocene periods. During this deformation, the movement on the Muráň fault changed to dextral and most probably, the secondary fan-shaped structures in Mesozoic rocks were formed during this time. These structures were originated after the Danian because sediments of the Gosau Group are incorporated into these structures. In the Late Eocene, activity of the Muráň fault began to gradually decrease and the fault structure is more or less covered by the Upper Eocene transgressive deposits of the Central Carpathian Paleogene Basin. The Neogene evolution is characterised by continuous change of the orientation of principal maximum axis $\sigma1$ from the NW–SE through N–S to NE–SW position. The Muráň fault started to be sinistral transpressional to transtensional up to normal fault but the movement along the fault was only several tens of metres. Quaternary period is characterised by extensional tectonic regime with the orientation of principal least axis σ_3 in WNW–ESE direction. Late Pleistocene to Holocene normal faulting is indicated by borehole analysis in the alluvial planes of the Rimava and Muráň rivers.

Acknowledgement: This research was supported by the Slovak Research and Development Agency under contracts No. APVV-17-0170 and Grant UK/357/2021.

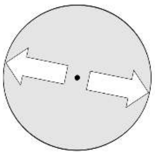
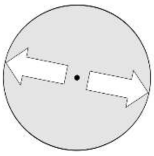
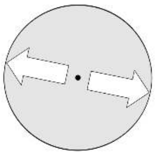
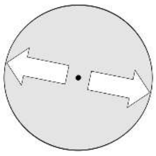
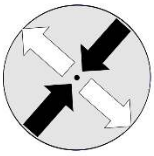
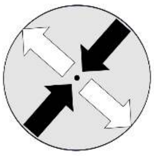
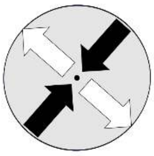
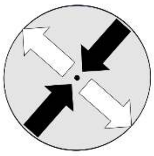
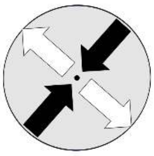
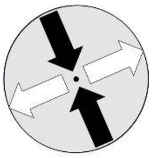
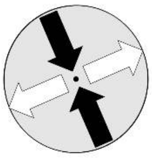
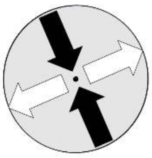
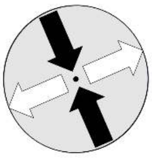
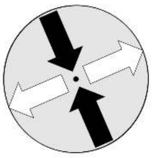
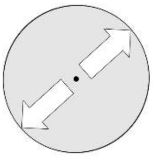
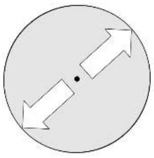
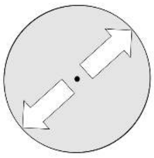
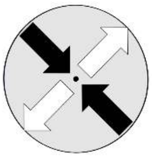
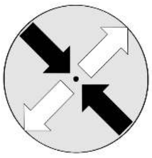
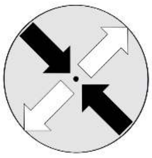
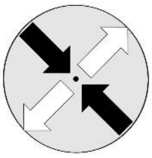
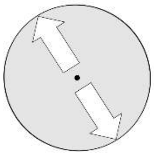
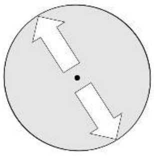
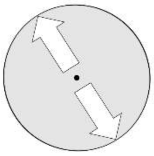
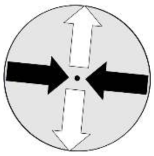
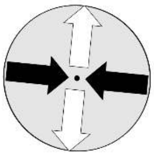
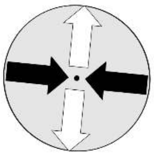
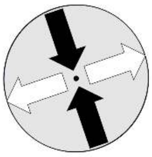
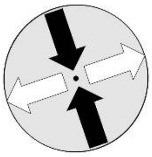
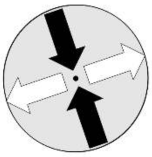
Observed rocks Appox. age of faulting	Triassic deposits	Veporic crystalline basement	Upper Cretaceous deposits	Upper Eocene - Lower Oligo. deposits	Tortonian volcanic rocks
Quaternary (< 2.6 Ma)					
Pliocene (5.3 – 2.6 Ma)					
Sarmatian – Pannonian (11.2 – 5.3 Ma)					
Badenian – Sarmatian (16.3 – 11.2 Ma)					
Eggenburgian – Karpatian (21.4 – 16.3 Ma)					
Priabonian – Chattian (37.7 – 23.0 Ma)					
Ypresian – Bartonian (56.0 – 37.7 Ma)					
Danian – Thanetian (66.0 – 56.0 Ma)					

Figure 1: Synthetic table of chronology for Late Cretaceous to Quaternary regional stress fields in the area of the Muráň Fault.

Anisotropy of magnetic susceptibility as a tool for understanding deformation of salt – example of a structural record in Kuh-e-Namak (Dashti) salt diapir in Iran

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The salt flow related deformation structures were studied in uniquely exposed salt body in Iran, the Kuh-e-Namak (Dashti) diapir, located ca. 100 km SE from the Bushehr city. This salt diapir body pierces through a crest of large anticline of the Zagros fold and thrust belt. Two glaciers of salt extend laterally from the dome and stretch downhill along the NE and SW slopes of the anticlinal limbs. Extruded salt belongs to the Hormuz sequence of Neo-Proterozoic to Early Cambrian age. Deformation structures in colored salt are well accessible in longitudinal valleys that carve into the dome and both glaciers. Continuous outcrops reveal a strain gradient associated with collapse of vertical fabrics in the dome during salt extrusion from the feeder below the dome and subsequent flow over the ridges of bedrock below the salt glaciers.

Anisotropy of magnetic susceptibility was employed to address the geometry of salt flow and deformation intensity, since mineral stretching lineation and flow fabrics in halite is difficult or impossible to measure in the field. Magnetic susceptibilities range from -10×10^{-6} to 200×10^{-6} SI and are generated primarily by hematite and paramagnetic impurities in rock salt (~1-12 vol.%), formed e.g. by anhydrite, quartz, microcline and phyllosilicates. Microstructural analysis revealed that the magnetic fabric symmetry and orientation is reflected by alignment of impurities in rock salt, which are parallel to the fabric of recrystallized halite grains. The AMS exhibits three main types of fabric symmetry on the basis of AMS clustering patterns in stereonets: 1) all K_1, K_2, K_3 directions clustered (orthogonal fabric), 2) K_1 directions clustered and K_2, K_3 axes forming girdles (linear fabrics), and 3) K_3 directions clustered and K_1 and K_2 directions forming girdles (flat/pancake shaped fabrics).

The strain gradient from the top of the dome to the tip of the northern glacier is characterized by six successive domains showing different macroscopic and magnetic fabrics. The dome of the diapir is dominated by alternating domains marked by steep and shallowly dipping fabrics explained by NE-SW trending collapse folds of colorful layered salt. In contrast, magnetic fabrics are regularly subhorizontal in this domain and show orthogonal symmetry of K_3 cluster type fabrics. In the upper portions of the northern glacier, below the plateau of the dome, the salt layering is dipping south at shallow angles and is crosscut by flat shear zones that are compatible with top to the north flow of salt into the glacier. Further NE, on steep flanks of the dome, macroscopic and magnetic fabrics show similar pattern, marked by a ENE-WSW stretched girdle of foliation poles compatible with collapse folds transposing the originally vertical, NNW-SSE trending planes. Flat plateau below the dome marks a zone of complete transposition, where the fold axial cleavage dipping southwest at moderate angles divides lithons of folded steep fabrics. Magnetic fabric conforms to the macroscopic new fabrics and shows additional subfabrics that are parallel with long axis of the glacier. Sheath folds are developed in flat plateau of the frontal part of northern glacier, where magnetic fabrics shows either flat orientations parallel with the salt layering, but also subfabrics showing steep orientation and longitudinal or transverse strikes with respect to the long axis of the glacier. Finally, fine grained salt mylonites in frontal termination of the glacier have flat layering associated with similar flat magnetic fabrics or magnetic fabrics that are again steep and strike parallel or perpendicular to the long axis of the glacier.

The disparity between the macroscopic fabrics and the magnetic fabrics is interpreted by a shorter strain memory of the magnetic fabrics that reflects the subfabrics of recrystallized halite grains. For example, in domains with relict vertical layering, the halite and concordant AMS fabrics are readily transposed into new, subhorizontal orientation.

Symmetry of the fabrics (orthogonal/K_1 clusters/K_3 clusters) also reveals zonality across the entire diapiric structure. While the top part of the dome and its slopes are dominated by orthogonal or clustered K_3 directions, the middle and frontal parts of the glacier show abundant orthogonal fabrics and clustered K_1 directions on edges of the glacier. This is compatible with extrusion of a viscous fluid in a channel confined by barriers and is similar to modeling results of fabric symmetry development during fluid extrusion on rigid surface.

Metamorphic and metasomatic evolution of the intermediate and mafic granulites at the interface between felsic granulites and garnet pyroxenites (Dunkelsteiner Wald granulite massif, Bohemian Massif)

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Dunkelsteiner Wald granulite massif is located in the Gföhl Unit of Lower Austria and consists mostly of felsic granulite with many smaller mafic to ultramafic bodies like eclogites, peridotites and pyroxenites, which are interpreted as tectonically incorporated mantle fragments into the upper crust during continental collision and subsequent exhumation. On the interface of felsic granulites with the mantle rocks, sometimes mafic and intermediate granulites with specific mineralogical and textural characteristics occur, showing that they could be a result of metasomatic and metamorphic processes between chemically contrasting lithologies.

Primary mineral assemblage of felsic and intermediate granulites included garnet, kyanite, quartz, plagioclase, K-feldspar and rutile and moreover in intermediate granulites clinopyroxene. The matrix mineral assemblage in intermediate granulite is then characterized by presence of orthopyroxene instead of clinopyroxene and kyanite breakdown to mixture of corundum and clinozoisite surrounded by garnet corona, while in the felsic granulite, the destabilization of kyanite is manifested by formation of plagioclase and garnet coronae.

Primary mineral assemblage of mafic granulites and garnet pyroxenites was similar and formed by garnet, clinopyroxene, and rutile. Some samples contain minor kyanite, sapphirine and quartz inclusions in garnet. The matrix mineral assemblage of the mafic granulites contains additionally aggregates of Ca-rich plagioclase grains hosting grains or symplectites of spinel and/or sapphirine, which are probably relics after kyanite. Metamorphic overprint of garnet pyroxenites is much less pronounced and is characterized by formation of orthopyroxene, plagioclase, amphibole, and diopsidic clinopyroxene. Texture of mafic granulites is characterized by formation of plagioclase around the garnet porfyroblasts and high amount of plagioclase inclusions partially or completely enclosed in the garnet rims. The matrix is formed by coarse-grained symplectites of Al-rich clinopyroxene with Ca-rich plagioclase and orthopyroxene.

In mafic granulites and garnet pyroxenites, clinopyroxene (up to 25 % of jadeite and 13% of CaTs) contains orthopyroxene lamellae and its composition is characterised by Na and Al decrease from the core to the rim. The chemical composition of garnets in both lithologies is characterized by a compositional plateau in the core with high Ca content. The rim composition is drastically affected by diffusion resulting in considerable Ca-depletion associated with enrichment in Mg and Fe in both lithologies. Primary garnet growth zoning in studied lithologies can be traced only by Cr-poor core.

Some garnets of garnet pyroxenites and mafic granulites contain Cl, Ba, K and Si rich inclusions in their cores, which could represent relicts after infiltration of fluid/melt from surrounding felsic granulites or could be relicts after earlier mantle metasomatism during subduction related processes. The mafic rocks are often showing heterogeneities on cm to dm scale and such textural and/or lithological transitions as for example from pyroxenite to more mafic granulite symplectitic texture are often marked by a Cr-enriched layer. This can be caused by presence of K-Cl rich fluids, during the rock evolution, because saline hydrous fluids appear to be efficient in transporting elements such as Cr during rock water interaction and could be also indicated by K-rich and Cr-rich network along grains in the matrix.

The whole rock geochemical analyses of studied lithologies has shown considerable chemical similarity of mafic granulites with garnet pyroxenites, but mafic granulites are depleted by MgO, FeO and LREE and enriched by K_2O, SiO_2, Al_2O_3 and Na_2O. Geochemical similarity is also obvious in the case of intermediate granulites and felsic granulites, but intermediate granulites are depleted by SiO_2, K_2O and TiO_2 and enriched by MgO, Al_2O_3, CaO, TiO_2 and LREE.

P-T evolution of the selected lithologies were estimated by thermodynamical modelling and various geothermometry calculations. Primary mineral assemblage of mafic granulites and garnet pyroxenites was formed in eclogite facies under conditions of 20-25 kbars and 1000 -1100 °C, then these rocks were almost isothermally decompressed to 10 kbars at 1100 - 900 °C. Metamorphic evolution of felsic granulite is characterized by decompression with temperature decrease starting at the eclogite-granulite facies transition at 16-18 kbars and 950-1100 °C to 8-10 kbars and 900-1000 °C. P-T evolution of intermediate granulites have slightly different trend -they were decompressed with temperature increase from 14-16 kbars and 800-900 °C to 8-10 kbars and 950-1000 °C.

The similarity of mafic granulites with garnet pyroxenites and felsic granulites with intermediate granulites in chemical composition and primary mineral assemblages can signify that mafic and intermediate granulites represent lithologies derived from garnet pyroxenites and felsic granulites, respectively, as a result of metasomatic processes at high temperature conditions at the contact of these chemically contrasting lithologies.

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Interaction between Early Devonian strike-slip shearing and thrusting in Oscar II Land, Svalbard

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Caledonian basement in the Svalbard Archipelago represents the northern extension of the Caledonian Orogen of Scandinavia and East Greenland. It is traditionally divided into three basement provinces. The eastern and northwestern provinces are commonly correlated with the East Greenland Caledonides, based on their similar tectonothermal histories. The Southwestern Basement Province represents the most enigmatic part of Svalbard's basement bearing correlations with the Pearya Terrane of Canadian Arctic, the Timanides, Franklinian Basin and the northernmost Scandinavian Caledonides. Using new structural and geochronological data, we aim to unravel the Late Caledonian evolution of the Southwestern Basement Province in Oscar II Land of Spitsbergen.

In the western part of Oscar II Land, the Late Meso- to Early Neoproterozoic Müllernesset Formation is unconformably overlain by Carboniferous strata and is surficially separated from the remaining basement by the Eurekan Svartfjella-Eidembukta-Daudmannsodden lineament. The micaschists and metapsammites of the Müllernesset Formation experienced two episodes of deformation and metamorphism. Structures formed during D1 and the associated M1 assemblage comprising quartz + muscovite + biotite + plagioclase + garnet + ilmenite are only found in locally preserved microlithons. The M1 event reached lower amphibolite facies conditions of 5-7 kbar at 500-560°C. It is strongly overprinted by M2 event and associated D2 deformation characterized by the development of a steeply SW-WSW dipping S2 foliation and stretching or mineral lineations plunging shallowly to SSE. The M2 metamorphic paragenesis formed under greenschist facies conditions outside stability field of garnet. Th-U-total Pb dating of retrograde monazite growing within S2 constrains the age of D2 to 410 ± 8 Ma. Monazite grains in rock domains less affected by M2 revealed an array of dates between 480 and 280 Ma. The Early Caledonian signal (c. 450 Ma) recorded by this monazite is interpreted to be related to M1.

The M1 event in the Müllernesset Formation can be correlated with the prograde stage of metamorphism and associated D1 related E-W compression recorded in the autochthonous basement of Oscar II Land and Prins Karls Forland. This event predates the northward thrusting of the Ordovician high-pressure (HP) Vestgötabreen Complex and overlying sediments onto the Oscar II Land basement at c. 430 Ma, which resulted in localized E-W trending folding in the underlying basement. The subsequent tectonothermal event is related to the activity of the NNW-SSE trending sinistral strike to oblique slip shearing in the western part of Oscar II Land. The timing of shearing is constrained by the aforementioned 410 ± 8 Ma retrograde monazite growth. The coeval greenschist facies overprint recorded in the Vestgötabreen Complex was a result of the formation of overturned NNW-SSE trending syncline and top to ENE thrusting. In the previously adjacent basement of Prins Karls Forland, the D2 related E-W contraction leads to reactivation and shortening of the top-to-W-SW overturned folds/nappe stack formed during the D1 event.

The sinistral shear zone recognized within the Müllernesset Formation may have continued along the Southwestern Basement Province to Wedel Jarlsberg Land. Here the Ordovician HP Berzeliuseggene unit is juxtaposed against low grade Caledonian basement along a similar NNW-SSE trending sinistral shear zone that was dated to 410 ± 18 Ma. The pre-Eurekan position of the Berzeliuseggene Unit would be exposed to the SW side of the NNW-SSE striking sinistral shear zone. In western Oscar II Land, the Ordovician HP unit is exposed to the NE of the coeval NNW-SSE trending sinistral shear zone in the Müllernesset Formation. The projection of these two NNW-SSE trending shear zones would connect in Nordenskiöld Land, where equivalents of the Vestgötabreen Complex were documented. Therefore, the sinistral shearing recorded in the Müllernesset Formation was most likely responsible for dismembering the Ordovician HP terrane along the Southwestern Basement Province. ENE-WSW shortening associated with NNW-SSE sinistral strike slip recorded in Oscar II Land resembles structures that are characteristic for oblique accretion and subsequent translational dismemberment of the terrane along continental margin, represented in Svalbard by the basement of Prins Karls Forland. Correlative structures have been recognized in the Pearya Terrane that was accreted to the Franklinian Basin of northern Laurentia in the Silurian to Early Devonian times.

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