ABSTRACT VOLUME

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ROZDROJOVICE ■ 24–27 APRIL, 2019

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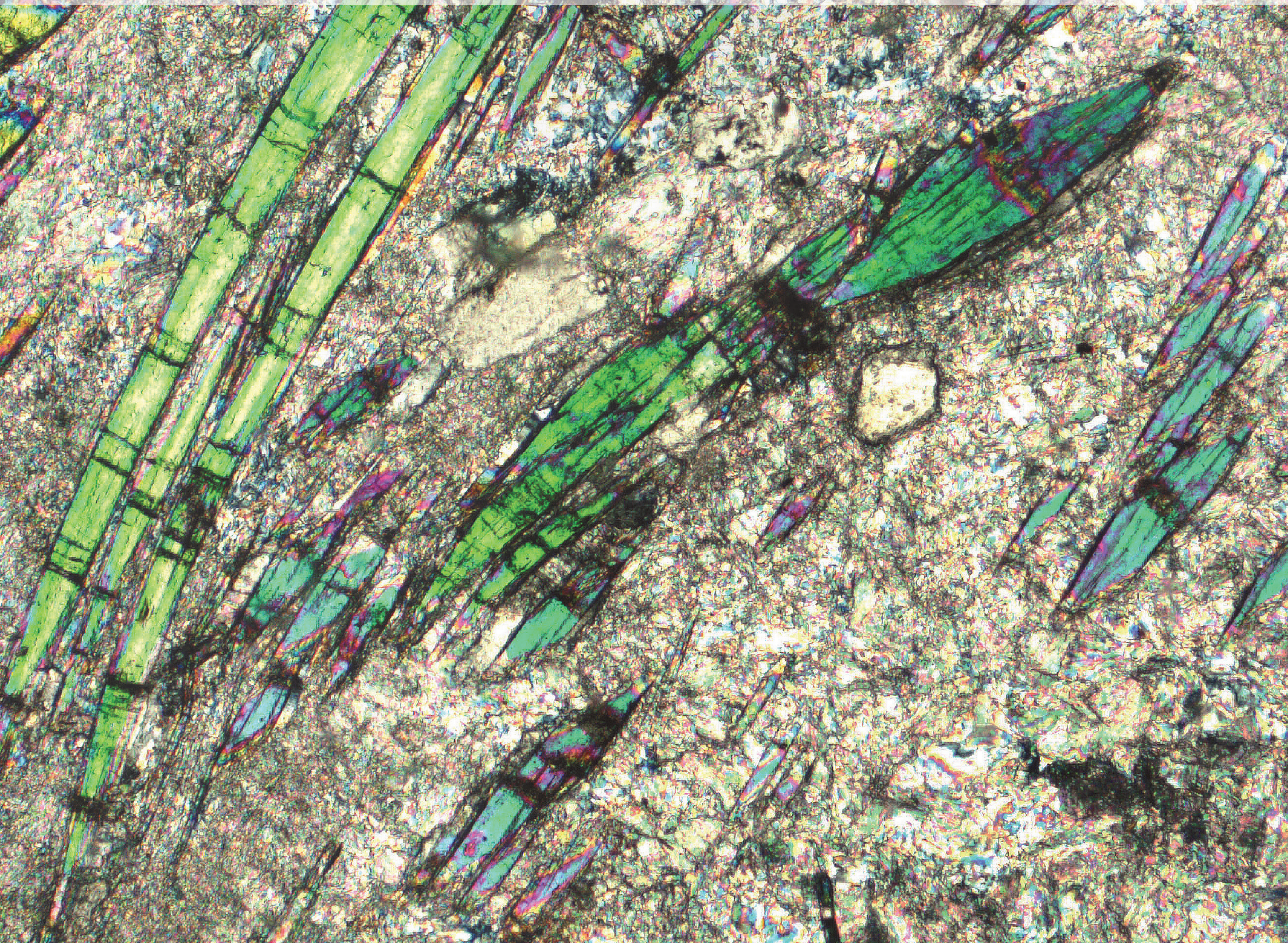
Edited by K. Hrdličková and L. Daňková



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Content

Migmatite formation in a crustal-scale shear zone during continental subduction: an example from a high-pressure granitic orthogneiss from the Orlica-Śnieżnik Dome (NE Bohemian Massif)

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Petrological study and pseudosection modelling have been carried out in high-grade orthogneisses of the southern domain of the Orlica-Śnieżnik Dome (NE Bohemian Massif). The studied samples are from an outcrop dominated by two deformation fabrics, a sub-horizontal S1 foliation defined by bands of recrystallized K-feldspar, quartz and plagioclase folded by centimetre– to several metres scale close to isoclinal folds associated with development of a new subvertical N–S trending foliation S2. Based on field features and textural observations, a gradual transition from banded mylonitic orthogneiss (Type I) to stromatitic (Type II), schlieren (type III) and nebulitic (type IV) textures typical of migmatities can be distinguished. The banded orthogneiss is composed of almost monomineral recrystallized K-feldspar layers (2 to 10 mm thick) alternating with layers of plagioclase and quartz (1 to 4mm thick), parallel to the S1 limb and the axial planar S2 foliation. The stromatitic migmatite shows 1 to 4 mm thick layers with macroscopically diffuse boundaries between plagioclase, quartz and K-feldspar rich domains. Boundaries between quartz and feldspar layers are poorly defined and interlobed with adjacent minerals. The schlieren migmatite is almost isotropic preserving small K-feldspar-rich domains within a matrix characterized by random distribution of phases, whereas in the nebulitic migmatite the microstructure is completely isotropic characterized by random distribution of phases. The transition from the Type I to IV is characterized by increasing nucleation of interstitial phases along like-like grain boundaries, by a decrease of grain size of all phases and by progressive disintegration of recrystallized K-feldspar grains by embayments of fine-grained myrmekite.

The mineral assemblage of all types consists of biotite, white micas, garnet, quartz, K-feldspar and plagioclase, and accessory apatite, ilmenite, zircon and monazite. In the mineral equilibria modelling, the core of garnet ($alm_{0.58}$, $py_{0.02-0.03}$, $grs_{0.34}$, $sps_{0.05}$) and phengite (Si = 3.38–3.20 p.f.u) is consistent with a P–T peak at 14−15 kbar and 650−700°C in the dominant g–bi–ph–ru–q–pl–kfs mineral assemblage. The garnet rim ($alm_{0.68}$, $py_{0.02-0.03}$, $grs_{0.11}$, $sps_{0.21}$) and white mica rim (Si = 3.10 p.f.u) together with unzoned biotite (XFe = 0.76–0.78) match the modelled isopleths in the middle-P part of the g–bi–ph–ilm–q–pl–kfs field to reach the solidus at 6–7 kbar and 630−650°C. Based on mineral equilibria modelling it is argued for fluid/melt-fluxed melting at HP conditions and on exhumation. The migmatite textural types are a result of grain-scale melt migration process and not of a localized melt transport in dykes as known from metasediments. In addition, the absence of prograde garnet zoning in the Type I to III suggests that the garnet was completely crystallized during the retrograde history, whereas in the Type IV the HP garnet chemistry was preserved. This can be explained by dehydration melting in a system open to melt migration and loss.

New geophysical data on the Sudetic Marginal Fault, SW Poland

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The Sudetic Marginal Fault (SMF), approx. 150 km long, is the most prominent morphotectonic feature in Poland. It bounds from the NE the Sudetic block of the northeastern Bohemian Massif, uplifted by up to 1500 m with respect to the Polish Lowlands in Late Miocene times. Earlier, its uplifted side was the northerly located Fore-Sudetic Block, whereas its Sudetic – now mountainous – side of it was downthrown, which resulted in deep erosion of the Fore-Sudetic Block, currently exposing much deeper crustal levels than those cropping out in the Sudety Mountains. Various aspects of the SBF have been studied and reported for almost 200 years, engaging e.g. such prominent geologists, as Eduard Suess and Hans Cloos. Available geophysical data concerning the SMF are, however, sparse to-date, apart from its manifestations on gravity or magnetic maps or few deep seismic (mostly refraction) sections, which render but the very existence of it. The here reported new data include several profiles of shallow geophysics, acquired using seismic, electrical resistivity tomography, very low-frequency (VLF) and radiometric methods and, also, three deep magnetotelluric sections, reaching up to depth of 4–5 km and 2–6 km long. The results of applying the above methods show various segments of the SMF to represent steep to vertical major fault zone of complex geometry, usually 0.5–2.5 km wide, comprising two or more main displacement surfaces, most probably accompanied by second-order fractures or fracture zones. The magnetotelluric sections show deeply reaching, steep, low-resistivity, 200–1000 m wide zones within the SMF, developed in crystalline or highly compacted and cemented Palaeozoic rocks, which most probably represent fracture-related acquifers, likely filled with thermal water. The acquired geophysical representation of the SMF, completed with its overall map pattern, is compatible with its interpretation as a chain of two or three Variscan major strike-slip fault zones that became recurrently reactivated in changing dip-slip regimes in successive Alpine tectonic events in Late Mesozoic to Late Cenozoic times.

Acknowledgement
The presented data were acquired in the frame of the research project “Young tectonic zones and the geothermal conditions in the Sudetes in the light of geochronological, structural and thermometric studies”, financed by the National Fund of Environmental Protection and Water Management in Warsaw and carried out at the Polish Geological Institute – National Research Institute.

Timescales of regional metamorphism and deformation in the continental collision zone: Eastern Himalaya, Sikkim, India

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The India–Asia collision is an archetype of the continent-continent collision. Reasonably well constrained conditions of plate convergence, well known gross structural evolution and its timing, and chiefly the lack of significant inheritance or overprinting by preceding or subsequent tectonothermal processes make the Himalaya particularly suitable for studying mechanisms and timescales of crustal deformation and metamorphism in response to the collisional process. One of the most debated features of the Himalayan orogeny is, present virtually along the entire length of the mountain chain, the inverted Barrovian metamorphic sequence. Its tectonic provenance and mechanism of formation remain contested despite decades long investigations. The Lesser Himalaya in the Sikkim region of the north-eastern India offer a unique inside into a well exposed, complete and coherent Barrovian sequence. In this study, we present geo- and thermo-chronological constraints on prograde and retrograde evolution of the Lesser Himalaya and the role of the Main Central Thrust in their metamorphism.

Lu–Hf garnet dating showed that the prograde metamorphism in the Lesser Himalaya commenced at about 18 Ma and completed by 11 Ma, when metamorphic peak was attained quasi contemporaneously in all metamorphic grades. Importantly, ages become older with increasing metamorphic grade suggesting that the structural inversion took place during retrogression. Zircon and apatite fission track ages point to rapid uplift and exhumation which immediately followed the metamorphic peak and brought the entire Lesser Himalaya sequence to the shallow crustal level within about 2 Ma. Distribution pattern of the cooling ages correlates with the domal structure which indicates that the Lesser Himalaya were uplifted and exhumed by the rise of the Teesta dome which dominates present day structure of the studied region. Rapid uplift was partially accommodated by high angle normal faults along which syn-kinematic leucogranites were emplaced probably as a result of decompression melting. Thermal modelling of track annealing in apatite indicates that the phase of rapid uplift finished at about 7 Ma. Since then, cooling continued at considerably slower pace. This transition coincides with the initiation of faster cooling period in the overlying Higher Himalaya.

Our data indicate that the formation of the inverted Lesser Himalaya Barrovian sequence as a response to simple overthrusting by extruding lower crustal migmatites along the Main Central Thrust is an unviable mechanism. Instead, our results are more compatible with a “tunnel” mode of the channel flow model. Rapid uplift and exhumation (within about 2 Ma) of the Lesser Himalaya was caused by the rise of the Teesta dome triggered by thickening linked to internal imbrication of small scale nappes and localized melting at deeper, mid-crustal level.

Acknowledgments
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Kinematics of active faults in the Eastern Alps

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Recent tectonic activity in the Eastern Alps is mostly concentrated in the system of strike slip faults that accommodate their east directed lateral extrusion. Present day activity of these strike slip faults is documented by several indirect geological, geophysical or geomorphological observations. However, none of the approaches has provided full characterization of present-day kinematic behaviour of particular faults. Here we present results of the first direct observation of fault activity at six sites (caves) in the Eastern Alps based on three dimensional movement monitoring. The sites are located in tectonically active areas close to major fault systems, which include Salzach-Ennstal-Mariazell-Puchberg Fault System, Mur-Mürz Fault System, Vienna Basin Transfer Fault, Periadriatic Line, and Pöls-Lavanttal fault system (Fig. 1). We had monitored subsidiary and/or conjugated faults associated to these major fault systems over a 1.5 – 2.5 -year observation period. Fault activity was recorded by high-resolution three-dimensional Moiré extensometers TM71, which recorded displacement of fault blocks in three orthogonal directions with resolution up to 1 µm. The measurements were registered automatically by web-cameras every 24 hours. The recorded fault activity was also compared to the seismicity near the monitored faults.

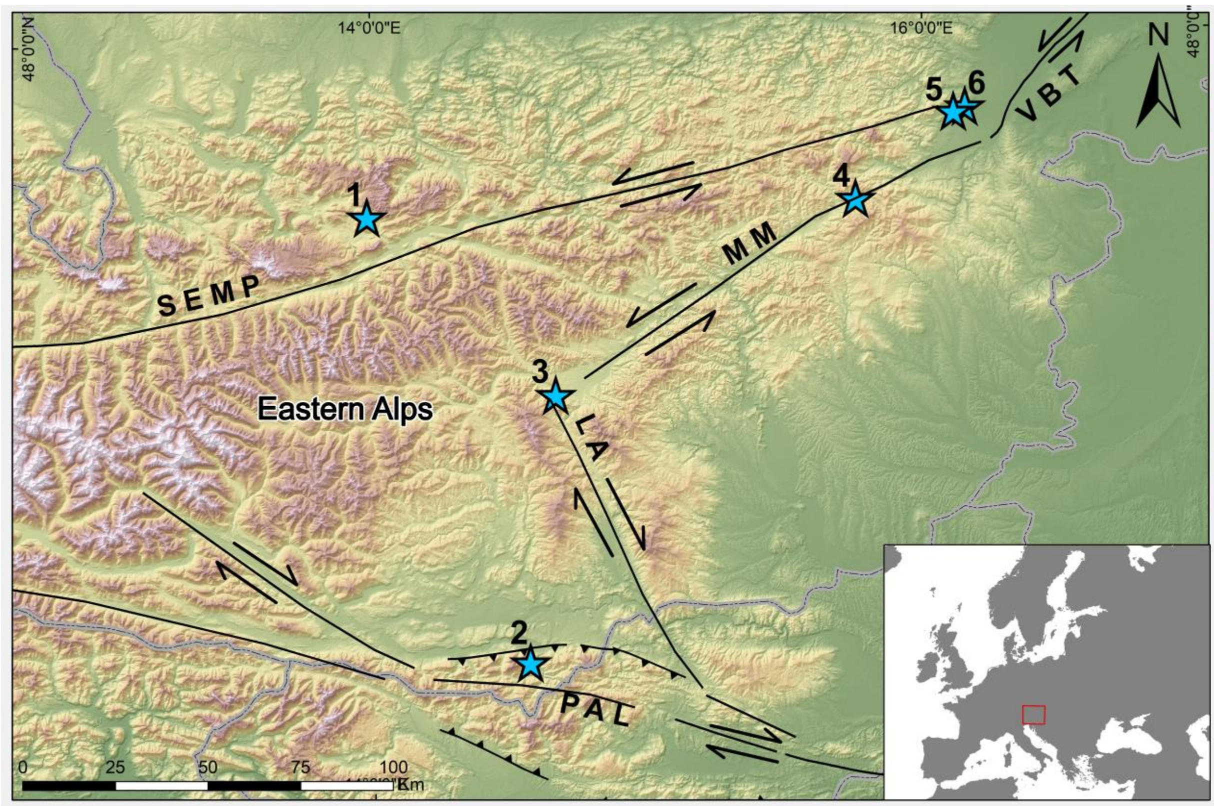

Fig. 1. Simplified sketch map of the main active fault systems in the Eastern Alps and the location of fault monitoring sites. 1 – Bullen Cave, 2 – Obir Cave, 3 – Geierkogel Cave, 4 – Zederhaus Cave, 5 –Emmerberg Cave, and 6 – Eisenstein Cave, SEMP – Salzach-Ennstal-Mariazell-Puchberg fault system, MM – Mur-Mürz fault system, VBT – Vienna Basin Transfer fault, LA – Pöls-Lavanttal fault system, PAL – Periadriatic Line fault system.

Monitoring network recorded aseismic displacements at micrometre level at all monitored faults during several activity phases that usually also coincided with periods of increased local seismicity. The annual displacement rates were mostly about an order of magnitude smaller than the rates of the entire crustal wedges revealed from the Global Navigating Satellite Systems. The biggest activity and average annual displacement rates were observed in the seismically most active regions along the Mur-Mürz fault, along the Periadriatic fault and in the North of the SEMP central part in Totes Gebirge Mts.

The particular displacements consisted of a variety of mechanisms and faulting regimes, such as strike slips, normal slips, reverse slips, displacements with movement component perpendicular to the fault plane (dilatation or compression) and their combinations. Fault dilations and compressions were mostly associated with thermal-volumetric variations, normal dip-slips and downward hanging-wall displacements originated due to gravitational relaxation or mass movement.

Displacements with the same mechanisms as their associated major fault systems or with an upward component were attributed to tectonic creep and strain built-up during the interseismic period. On the other hand, the countervailing displacements opposite to the master fault kinematics were most probably caused by elastic rebound. They were usually registered few days in advance to distinct local earthquakes that were simultaneously activated at locked segments within the same deformation band. Therefore, the countervailing events could be considered as an indicator of impending near earthquake within the rebound zone.

Tectonics of durbachitic rocks in the southern part of the Třebíč Pluton

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The study is focused on the tectonics of rock in the southern part of the Třebíč Pluton, which is a plutonic body consisting of durbachitic rocks situated in the SE part of the Bohemian Massif. The pluton intruded into the Variscan orogenic root (Moldanubian Unit) before 335–340 Ma (Kotková et al. 2010). Orientation of structural anisotropy was measured on the outcrops and quarries in the field. Anisotropy of magnetic susceptibility (AMS) was used to characterize both the rock fabric and the degrees of preferred orientation, which well reflects magmatic- and strain-originated preferred orientation of magnetic minerals.

AMS data were obtained from 192 samples taken at 25 localities south of the Třebíč fault in durbachite and granite. Results of AMS analysis were compared with mesoscopic structural observations (compass data). Based on obtained results, it can be assumed that the durbachite intrusion was deformed several times.

The degree of magnetic susceptibility (K_m) varies from 9.4×10^{-5} to 1.08×10^{-4} SI. The value of degree of anisotropy increases from south to north. The shape parameter T varies from strong prolate (−0.820) to medium oblate (0.510). Vectors $\mathbf{K}_1$ show magnetic lineations developed in NW–SE direction and plunging to the NW or N under low angels. Vectors $\mathbf{K}_3$ are normals to magnetic foliation (Fig. 1). The vectors are steeply dipping mostly to the W.

There was also used an analysis of temperature dependence of magnetic susceptibility. This method showed that all fabrics in these rocks in southern part of pluton are controlled by paramagnetic minerals such as amphibole and biotite.

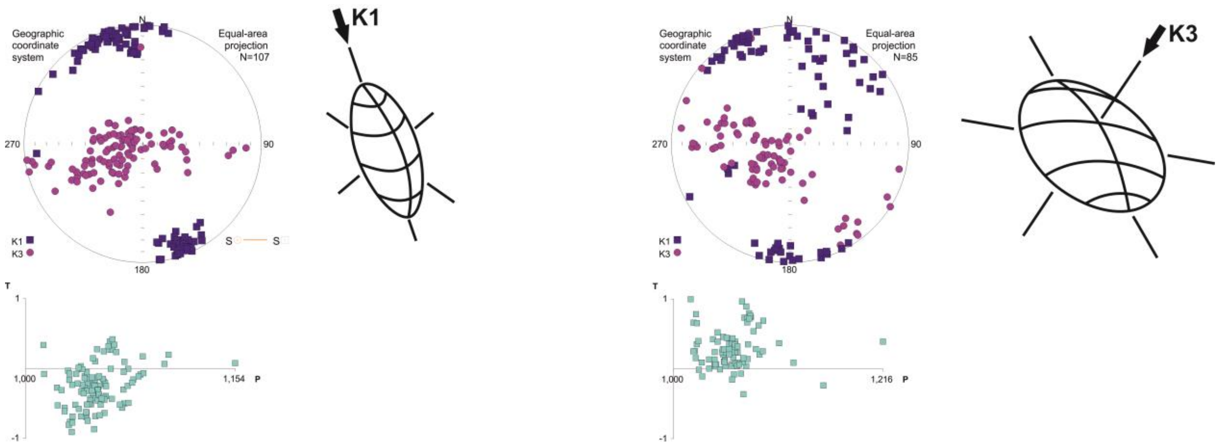

Fig.1. Orientation of magnetic lineation $\mathbf{K}_1$ and poles to magnetic foliation $\mathbf{K}_3$ in durbachitic rocks from the southern part of Třebíč pluton (left – southernmost part, right – central part). The shape parameter T varies from strong prolate (−0.820) in the south to medium oblate (0.510) in the center.

Acknowledgments

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Heavy mineral-based provenance analysis of Cretaceous synorogenic sandstones from the Klape Unit, Poruba Formation and some controversial units

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Presence of exotic detrital components in the synorogenic sedimentary rocks of the Western Carpathians result from large-scale tectonic processes in the Tethyan realm during the end of the Early Cretaceous. These paleogeographic changes led to formation of accretionaly wedges, obductions and in the end to massive input of detritic material to adjacent basins. This exotic material occuring in the Albian–Cenomanian sandstones is the only one preserved imprint of the closing old Triassic ocean branches in Western Carpathian area. The oldest appearance of exotic components is recorded in the sandstones of Klape Unit in Pieniny Klippen Belt and in Poruba Formation, which reflects flysch development of Tatric and Fatric Unit in the northern (external) zones of Central Western Carpathian. The topic of psephitic exotic material was the subject of long-years interest of several scientists and numerous analyses were done, but psammitic fraction has not been analyzed in detail up to this day.

Our research provides results of the first comprehensive analysis of the heavy mineral assemblages from the oldest exotic-bearing units in Western Carpathians. We collected 37 samples from sandstones of Klape Unit, Tatric & Fatric Unit (Poruba Formation) and some adjacent units for heavy mineral analysis in total. Majority of the studied rocks are calcite-cemented litharenites. They have very low content of feldspars and variable ratio of quartz and lithic grains (mostly quartzites, carbonates, basaltic volcanics, less phyllites, mica-schists and silicites). Comparison of the heavy mineral assemblages from the above mentioned units showed that the composition of majority analyzed samples is mainly rich in chrome-spinels, zircons, tourmalines, apatites and rutiles in various ratios. The studied sandstones are poor in garnets but there occur also sporadic enriched samples. The amount of titanite, kyanite, monazite and epidote is low, silimanite and staurolite are very rare. Some samples are enriched by blue amphiboles, pyroxenes and kyanite.

According to the provenance analysis, the spinels were derived from harzburgitic ophiolites. However, their composition overlaps in some parts with chromitites and cumulates fields. The TiO_2 vs. Al_2O_3 diagram showed that most of the spinels come from the supra-subduction zone peridotites; some aluminium-depleted and higher-titanium grains best fit to the volcanic arc field. The examined blue amphiboles were identified as glaucophanes to ferroglaucophanes. They were derived from HP/LT metamorphosed basaltic rocks in a subduction zone. The pyroxenes are represented by orthopyroxenes (enstatite) and less clinopyroxenes (augite, diopside). Because of their common euhedral shape and fresh look we assume that they probably did not share the same ophiolitic source as Cr-spinels and blue amphiboles. They rather come from some nearby and time-parallel volcanic rocks rather of calc-alkaline provenance. Majority of the studied tourmaline grains was unzoned however, some of grains were intergrown in a poikiloblastic patterns. Tourmaline grains come from different types of metasediments. Almost all tourmalines from Havranský vrch Hill rather come from Li-poor granitoid rocks.

First, the research results showed that presence of Cr-spinels, blue amphiboles and possibly mosaic tourmaline is linked with an ophiolitic source. Second, rest of heavy minerals like zircon, tourmaline and rutile probably were derived from older sediments. Metamorphic rocks of various degrees of metamorphism were relatively rare, as evidenced by garnet, staurolite, kyanite and sillimanite. Third, the examined units probably shared the same source as no considerable distinctions were noticed among them.

Acknowledgements
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Two geotectonic types of S-type granites in the Tribeč Mts.: their possible evolution revealed by zircon SHRIMP dating

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Variscan granite bodies form parts of the crystalline basement within the recent Alpine fabric of the Western Carpathians. Granitoids represented by granites and granodiorites are classified as S-type, whereas most of tonalities and granodiorites belong to the I-type suite. Both suites have volcanic arc setting as the product of subduction related regime. Ages of the Variscan Western Carpathians granites, alike the Variscan European belt ones, indicate a relatively early origin (e.g. Kohút et al. 2009, Broska et al. 2013). Such I- and S-type granite bodies were identified also in the Tribeč core mountains. On the basis of new SHRIMP and CHIME dating the S-type seems to have originated in two geotectonic events, which are characterised by following features. The older S-type granites are coeval with the I-type granites originated at Devonian/Carboniferous boundary according to recent SHRIMP datings (363 Ma). The analogous age of the significantly overprinted granites, having S-type character still preserved in bulk rock composition, in apatite, biotite composition and by the presence of monazite, was recognised in the Tribeč ridge zone nowadays. The younger undeformed S-type granite dyke (CHIME dating 342 ± 4.4 Ma; Broska and Petrík 2013) intruded into older S-type granites, what post-dates the alteration process and possible stacking of the granite bodies resulting in granite duplex with low-angle superposition of deformed granite over undeformed one. Recent SHRIMP dating determines the Visean age (334 Ma) of highly evolved S-type granites, which were preserved in cupolas within the older Variscan crystalline basement. The evidence for such evolution besides strong greisenization (total degradation of feldspars and formation of quartz–white mica assemblages) is abundant tourmaline with high dravitic molecule, the presence of Mn-rich apatite, monazite and zircon with special composition. Except Mn-rich apatite also abundant tiny stoichiometrically pure apatite grains are present, which were probably exsolved from feldspars enriched in phosphorus, a process commonly known from highly evolved granite systems. The Visean leucogranites enriched by Nb-rich rutile were described by Uher et al. (2018) in the eastern part of the Tribeč Mts. These fine-grained granites known from valley Topoľnica, ~3 km SW from Skýcov and from locality Večerová, ~5 km NE from Skýcov are composed of quartz, Kfs, An_{10} and muscovite with accessory phases such as zircon, rutile, monazite-(Ce), xenotime-(Y) and locally with thorite/huttonite–cheralite–xenotíme-(Y), uraninite, columbite-(Fe)/ixiolite and minerals of pyrochlore group. This special mineralisation supports an evolved crustal character of granites. Summarising data the large Tribeč granite body is composite and formed by: (***1***) older subduction-related I and S type tonalites/granites (ca. 360 Ma), and (***2***) younger intrusions of the syn-collisional granite bodies (ca. 334 Ma) reflecting collisional tectonic event of the Variscan orogeny. The high fluid activity during collisional event triggered local massive granite alteration.

Acknowledgments
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Study of syn-tectonic intrusions of the Moroccan Meseta (High Moulouya and Jebilet massifs): contribution of remote sensing data and zircon U-Pb geochronology

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The High Moulouya and Jebilet massifs are located in the Moroccan Meseta domain which is affected by Devonian – Early Carboniferous extension (dismembering of the North Gondwana margin) and late Carboniferous to early Permian collision forming the North African Variscan belt. It is considered as a young prolongation of the European Variscan belt at the North Gondwana margin. The Meseta is divided into a western and eastern domain, the later exposing early deformational structure interpreted as an eovariscan orogenic event.

The High Moulouya massif belongs to the eastern Meseta and is considered to be situated in the most internal zone of the eovariscan belt because of its relatively high regional metamorphic grade (Bt zone) affecting the cambro–ordovician schists compared to the adjacent massifs that are metamorphosed in lower grades (Chl–Mu zone). This basement is intruded by several granitoids with ages ranging from upper Devonian to Late Carboniferous (Rb/Sr, U/Pb TIMS). However, only few data exist regarding the relation between deformation of host rocks and emplacement of granitoids.

The Jebilet massif belongs to the western Meseta. It is made of a large Visean intracontinental basin associated with bimodal magmatism (mafic sills, granitic intrusions) and a strong LP–HT metamorphism (Crd–And zone). Late Carboniferous to early Permian thrusting and folding affect heterogeneously the basin and its basement.

This work present new geochronological data (U/Pb LA–ICP-MS) on magmatic intrusions and lithological and tectonic map of High Moulouya and Jebilet massifs. The goal is to reassess the tectonic evolution of both granitoids massifs by combining remote sensing structural geology and geochronology.

Preliminary geochronological results highlight a cluster of magmatic pulse at 330–335 Ma for both massifs In the High Moulouya massif, the results rule out a long-lived magmatic activity proposed by previous authors (Clauer et al. 1980, Tisserant 1977, Oukemeni et al. 1995) which is now restrained to Visean exclusively. In the Jebilet massif, this crystallization age is concordant with published data showing a strong magmatic activity during this time.

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The origin and pre-Variscan development of high-grade rocks of the Krušné hory as revealed by LA–ICP-MS zircon geochronology and whole rock geochemistry

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The Krušné hory (or Erzgebirge), located on the southern margin of the Saxothuringian Domain, is composed of a crystalline 'Cadomian' basement overlain by a complex nappe pile of ortho and paragneisses, schists, and metabasites, which locally preserve Variscan HP or UHP metamorphic conditions. In this study a representative suite of metasedimentary and orthogneiss samples from the Krušné hory have undergone U–Pb zircon geochronological and whole rock geochemical characterisation.

Samples of paragneiss, quartzite, and white schist reveal similar detrital zircon patterns; the majority of data (c. 75 %) falls within the age range 530–720 Ma, with prominent peaks at c. 570 Ma and 630 Ma. Subordinate Tonian, Palaeoproterozoic, and Neo-Archaean peaks are also recognised. A migmatitic sample shows a similar detrital zircon record, but, also additional peaks at the Cambro-Ordovician, Siluro-Devonian, and Devono-Carboniferous boundaries associated with structure-less zircon rims and systematically lower Th/U ratios.

Zircon from the orthogneiss samples also show strong inheritance; however, concordant ages older than 700 Ma are scarce. Augen orthogneiss associated with eclogite-facies lithologies display discrete inherited maxima between 650 and 520 Ma and emplacement ages 500–480 Ma. A trend of decreasing Th/U ratios in zircon is observed to c. 500 Ma, after which significant increases in both the trend and variability of the data is observed. In contrast, orthogneiss from the structurally lowest portion of the Erzgebirge show only limited inheritance and older emplacement ages (540–500 Ma). These orthogneiss, which locally contain ptygmatically folded leucocratic bands, also exhibit discrete zircon rims that yield younger (c. 480–490 Ma) ages associated with low (< 0.1) Th/U ratios.

All of the samples show compositions comparable to Upper Continental Crust compositions with a small Nb–Ta negative anomaly. Two outlier samples, one orthogneiss and one paragneiss, show depletion in Ba, Sr, Ti, and HREE, a pronounced negative Eu anomaly and minor enrichment in Ta. Geochemical data for the metasedimentary rocks all show 'continental island arc' affinity and 'active margin' signatures are preserved in all orthogneiss samples except the outlier, which shows a 'syn-collisional granite' or 'within plate volcanic zone' signature. However, the limited chemical variation between different lithologies of different ages suggests significant recycling and that the geochemical signature is more likely controlled by country rock than tectonic environment.

On the basis of this new data, as well as existing data from other parts of the Krušné hory, it is proposed that the Krušné hory represents a giant accretionary complex. The transition from a 'Cadomian' active margin to an extensional regime occurred in the Early Cambrian, coinciding with repeated magmatic pulses triggering a hot geothermal gradient, recycling of fertile crust, high-temperature metamorphism and cratonisation of relatively young material. This transition is further reflected in the detrital Th/U record in zircon which shows significant increase in both absolute values and variation during the Late Cambrian/Early Ordovician reflecting the change to a higher temperature environment.

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Character of crustal-derived fluids metasomatizing mantle wedge: constraints from minerals in multiple solid inclusions

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Garnet peridotites associated with ultrahigh-pressure metamorphic (UHPM) rocks in the Saxothuringian domain of the northern Bohemian Massif show bulk trace element and isotopic characteristics, which suggest their cryptic metasomatism by subduction-related fluids (Medaris et al. 2015). Multiple solid inclusions (MSI) discovered in garnet from lherzolite and harzbugite provide direct evidence for crustal metasomatism of the mantle wedge and their mineral assemblages and mineral compositions allow constraining character of metasomatizing crustal-derived fluids.

The MSI in garnet lherzolites and harzburgites are concentrated in a ~ 200–500 µm wide annulus at the rim of garnet, whereas the garnet cores are inclusion-free. The MSI contain mainly amphibole, barian mica, magnesite and dolomite with minor clinopyroxene, orthopyroxene, garnet II, spinel, magnesiochromite, and accessory thorianite/uraninite, apatite, monazite, graphite, pentlandite, scheelite, and norsethite. Mineral assemblages of the MSI and chemical composition of minerals in MSI are variable depending on the rock type (lherzolite vs. harzburgite). Amphibole strongly prevails over magnesite (± dolomite) and barian mica in lherzolites, on the other hand, carbonates (dolomite > magnesite) and barian mica dominate over minor amphibole/clinopyroxene in hagzburgites.

Barian mica represents a solid solution of phlogopite $KMg_3(Si_3Al)O_{10}(OH)_2$ and kinoshitalite $BaMg_3(Al_2Si_2)O_{10}(OH)_2$ with 0.24–0.67 apfu Ba and it is rich in Cr (0.03–0.22 apfu Cr in lherzolite; 0.23–0.50 apfu Cr in harzburgite) and Cl (up to 0.34 apfu) (see Čopjaková and Kotková, in press). Amphibole is pargasite with high Na (2.7–5.6 wt. % Na_2O), Cr (0.9–2.5 wt. % Cr_2O_3 in lherzolite, 2.5–3.8 wt. % Cr_2O_3 in harzburgite) and Cl/F ratio 1–4. Similarly, clinopyroxene is rich in Na (3.3–8.7 wt. % Na_2O) and Cr (1.3–2.6 wt. % Cr_2O_3 in lherzolite, 2.3–3.9 wt. % Cr_2O_3 in harzburgite). Spinel group minerals vary in composition from spinel in lherzolites to magnesiochromite in harzburgites. Apatite corresponds to Cl-apatite with high Cl/F ratio (3–13) and LREE enrichment. Monazite shows extreme LREE enrichment with predominance of La over Ce and high Th contents (up to 0.2 apfu).

XMg and Cr contents in MSI reflects the composition of the host lherzolite and garnet, the latter providing source of Al. On the other hand, LREE, LILE, CO_2, H_2O, Cl, F, Na, P, Th and U enrichment reflect contribution of crustal-derived fluids. At UHP–UHT conditions recorded by the associated diamond-bearing metasediments (c. 1100°C and 5 GPa; Haifler and Kotková 2016) located above the second critical point in the pelitic system, solute-rich supercritical fluids with properties of a hydrous melt are produced. These fluids represent efficient carriers of chemical elements from the subducting slab into the overlying mantle wedge. The composition of the MSI suggests that the hydrous carbonatitic – silicic fluid infiltrated lherzolites and interacted with them. During this interaction, the chemical composition and physical properties of the fluid changed, becoming poorer in alumosilicate components and richer in CO2 thus less viscous in harburgites compared to lherzolites.

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Geodynamic classification of the Lower and Middle Miocene coarse-grained sediments in Vienna Basin and Blatné depression (Danube Basin)

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Geological boundaries, or the contact between Eastern Alps and Western Carpathians, are situated under the Neogene sediments of the Vienna. The Vienna Basin is an SSW–NNE oriented Neogene basin of about 200 km length and 55 km width. The Neogene sedimentary succession, reaching up to 5500 m of thickness in the central part of the basin, is documented by numerous wells and relatively dense network of seismic profiles. The Blatné Depression located in the NW part of the Danube Basin represents the northernmost sub-basins of the Pannonian Basin System. Its subsidence is associated with oblique collision of the Central Western Carpathians with the European platform, followed by the back-arc basin rifting stage in the Pannonian domain.

By combination of sedimentological and biostratigraphic analyses, interpretation of well-log curves and their mutual correlation, as well as by interpretation of seismic profiles using seismic stratigraphy methods, a complex image of paleoenvironment, transport mechanism and distribution of sedimentary facies in time and space has been achieved.

During the Lower and Middle Miocene, several significant tectonic activities took place, during which the coarse-grained sediments were deposited. These sediments include clasts of rock sequences after exhumation and denudation of Alpine and Carpathian units. The chronostratigraphic division reflects only the position in the sedimentary fill. The suggested division takes into account geodynamic processes, which results the sedimentation of conglomerates. There are also separate groups, which help understand the distribution of conglomerates and their transport from different parts of exhumed units.

Geodynamical classification of coarse-grained sediments of Low./Mid. Miocene					
Age/stage		NN zones	Conglomerates	Geod. Classification	Paleoenvironment
Badenian	Late	NN 6	Devínska N. Ves (Vienna Basin) and Doľany cong. (Blatné depres.)	marginal cong. connected by exhumation of Malé Karpaty Mts.	Alluvial fan
	Early	NN 5			
		NN 4	Jablonica Group (Vienna Basin) and Cífer cong. (Blatné depres.)	conglomerates sedimented near active transtensional and normal faults	Delta to fan delta
Karpatian					
Ottnangian					
		NN 3	Planinka Fm. and Záhorie Group (Vienna Basin)	conglomerates of "piggy back" basins	Littoral zone
Eggenburgian		NN 2			

Fig. 1. Suggested geodynamic classification of the Lower and Middle Miocene coarse-grained sediments.

For the period of the Lower – Middle Miocene, three possible geodynamic environment can be considered (Fig. 1): (i) conglomerates of the „piggy-back“ basins of Eggenburgian to Ottnangian age (Zohor Group, which includes Eggenburgian Chropov, Wintenberg, Podbranč and Dobrá Voda conglomerates; Ottnangian is represented by conglomerates of Planinka Fm.) (ii) conglomerates sedimented near active transtenze and normal faults of upper Ottnangian/Karpatian to Lower Badenian age (Jablonica Group, which is limited for Vienna Basin, includes Jablonica conglomerates (Lakšáre Fm.) and Zohor conglomerates (Lanžhot Fm.), while in the Blatné depresiion the Cífer conglomerates are present) and (iii) marginal conglomerates connected by uplift of the Malé Karpaty Mts. of the Upper Badenian age (Vienna Basin – conglomerates of the Devínska Nová Ves Fm.; Blatné Depression – Doľany conglomerates).

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Arc magmatism evidences in the Mariánské Lázně Complex – Čistá pluton and new insights from Hf analyses

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The Mariánské Lázně Complex (MLC) crops-out at the boundary between the lower (Saxothuringian) and upper (Teplá-Barrandian) plates in the NW Bohemian Massif. Strongly retrogressed eclogite bodies in the MLC show peak eclogite-facies metamorphic conditions at c.390 Ma and are affected by HT extensional shearing at c.375 Ma connected with granulite-facies overprint and migmatization. To better understand the geodynamic context for this rapid transition from cold subduction to hot extension, rocks from the extensional zones have been studied. These rocks are dominated by amphibolite migmatites and contain unfoliated, fine- to coarse-grained rocks in which magmatic textures, including euhedral crystal shapes, magmatic bedding and/or dykes, are preserved. In places, the unfoliated structure of the magmatic rocks passes into magmatic foliation and locally to solid-state amphibolite-facies shear zones. The nature of these magmatic rocks ranges from amphibole gabbros to trondhjemites, the latter being previously dated giving a Devonian age. This magmatic event in the deep crust has a possible upper crustal equivalent in the granitoids of the Čistá pluton, intruding the hanging-wall Teplá-Barrandian domain. This study provides new whole-rock geochemical data including Sr–Nd isotopes and majorand trace elements, combined with zircon U–Pb geochronology and Hf isotopes, for the MLC and Čistá magmatic rocks. The calc-alkaline nature of the rocks, a pronounced negative Nb–Ta anomaly, relative enrichment of fluid-mobile elements (including LILE), strong fractionation of LREE over HREE and depletion of high field strength elements (HFSE) is evidence for an active continental margin origin. Low values of εNd data suggest either the presence of variable mantle chemistry at the base of the magmatic system, and/or implication of the lower crust. Zircons from the gabbro to trondhjemitic rocks of the MLC show magmatic overgrowths with ages ranging from 390 to 370 Ma and strong inheritance between 480 and 560 Ma. Zircons from the Čistá pluton show two peaks with age range of 350–380 Ma and 380–410 Ma, together with a weak 500−530 Ma inheritance for one sample. The results are interpreted in terms of a long-lasting magmatic activity covering most of the Devonian. During this period, magmas intruded the lower crust during the Middle and Late Devonian and were emplaced in the upper crust during the Early Carboniferous. Samples show strong involvement of the Cambrian lower crustal material, including the eclogites, and, based on variable relative enrichment of mobile elements (LREEs and LILEs) among the samples, a possible heterogeneous contribution of the subduction component into the system. Zircon in-situ Hf isotope study shows firstly that there was not only juvenile input to produce the Devonian magmatism, which is in accordance with the recycling recorded by the geochronology, and secondly, the model age of the oceanic lithosphere involved in the system is not Ordovician but older, showing at least late Neoproterozoic ages.

Late Palaeozoic palaeomagnetic and tectonic constraints for amalgamation of Pangea supercontinent in European Variscan Belt

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A review of the evolution of palaeomagnetic directions and sequence of tectonic events in the European Variscan belt and Gondwana and Baltica during late Palaeozoic times is presented. The early Carboniferous paleomagnetic records indicate a 70 ° anticlockwise rotation, while late Carboniferous to Permian magnetic directions are consistent with 120 ° clockwise rotation of the eastern and central parts of the Variscan belt. The chronology of tectonic events based on geochronologically constrained deformation, metamorphic and magmatic events can be discretized into five principal events 80 Ma long. In this model the Variscan belt is regarded as a linear sub-plate isolated from Gondwana and Laurussia by the Rhenohercynian and Palaeotethysian oceans during Devonian times. This linear composite belt was segmented by transform faults and boundaries in the late Devonian to early Carboniferous times (360–335 Ma) during closure of Rhenohercynian ocean synchronously with collision between Saxothuringian and Moldanubian blocks. Subsequent relocation of subduction to the northern boundary Palaeotethysian ocean was responsible for N–S shortening almost orthogonal to the ancient sub-plate N–S elongation at around 335–325 Ma. This deformation resulted in dextral reactivation of transform boundaries associated with anticlockwise rotation of intermittent blocks. At the end of this rotation, the faults were parallelized to the Teysseire–Tornquist zone – the southern margin of Baltica, while the lozenge-shaped blocks of the former Variscan sub-plate were further shortened during continuous contraction. Subsequently, the Variscan belt suffered a giant transtensional event from 325 to 310 Ma that was related to the development of extensional syn-magmatic core complexes over the whole belt and significant dextral reactivation of earlier NW–SE trending transform faults. The whole system subsequently suffered a period of NNE–SSW shortening that affected the Variscan belt namely along the former Laurussian and former Variscan sub-plate contact in the north and in the south, where the giant Cantabrian orocline developed at around 310–297 Ma due to hard collision with Gondwana. The final stage of rapid clockwise rotation is attributed to giant N–S extension affecting the whole Variscan belt at the onset of Permo-Triassic. This complex evolution is regarded as a result of the readjustment of inhomogeneous and thermally and mechanically instable mobile space in between reorganizing the Gondwana and Laurussia megaplates and the opening of the Palaeotethys ocean during the final stages of formation of the Pangea supercontinent.

Miocene structural evolution of the SW part of the Pannonian Basin: not only extension but compression and transpression

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The Pannonian Basin traditionally considered as extensional basin formed in the hinterland of the coeval Carpathian fold-and-thrust belt (Royden and Horváth 1988). Surface and subsurface structural analyses revealed, however, a more complex scenario. This part of the basin is characterised by large-scale, low-angle brittle normal faults and deeper ductile shear zones, as predicted by earlier works of Tari (1994), Tari et al. (1996) and Fodor et al. (2003). A great number of secondary tilted blocks and grabens occur in the hanging wall of the two major detachment faults. Syn-tectonic sediments constraint the age of major extensional faulting to ~ 17.2–15 Ma. This is in agreement with exhumation of metamorphic footwalls exposed in the Rechnitz window and Pohorje Mts. while syn-extensional exhumation of the 18.65 Ma Pohorje intrusion extend extension up to ~18.5 Ma. This extensional domain is bounded on the south by the Periadriatic-Balaton and Mid-Hungarian shear zones, which acted as transfer faults during extension.

In the exposed part of the basin (Bakony Hills), dextral strike-slip faults are well-known elements (Mészáros 1982) and are associated with oblique or pure reverse faulting and folding (Kiss – Fodor 2007). New overview of borehole data indicates extensive underthrusting of Oligocene below Mesozoic rocks. The age of this transpressional or contractional deformation is poorly constrained; some could be late Middle Miocene or earliest late Miocene, all coeval with late-stage syn-rift deformation.

In the SW basin part, below thick late Miocene cover, strike-slip faults bounds domains characterised by normal faults and domains, mainly close to the Balaton zone, marked by pure contraction and/or strike-slip faults. Although strike-slip faults were recognised in other parts of the Pannonian basin (e.g., Tari et al. 1992), pure contraction seems to occur only in its southern part.

In this basin parts the thick Late Miocene sediment succession reveal more detailed time constraints on contraction: it was more or less continuous between 11.6 and ~8.5 Ma, a period classically considered as the post-rift phase. In fact, the presence of contraction was considered to mark the onset of neotectonic phase, and dated as 8–7.5 Ma (Uhrin et al. 2011), but new data clearly point to a much older onset of folding.

The late Middle Miocene to recent shortening is coeval with thrusting and folding of all areas from the Southern Alps to the SW Pannonian basin. However, the amount of deformation is eastward decreasing, and in the Pannonian basin, the shortening derived from plate tectonic forces was overprinted for long time by the local lithospheric process guiding thermal subsidence. The onset of neotectonic phase can be placed at the moment when contraction-related uplift exceeded thermal subsidence and rocks started to be eroded.

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The Protocarpathian continent: a fragment of Brunovistulia?

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The Carpathians are a mountain belt of Alpine age, stretching c. 1300 km from Austria through the Czech Republic to Poland, Slovakia, Ukraine and Romania. The Western Carpathians are subdivided into the Central Carpathians and the Outer Carpathians, separated by the Pieniny Klippen Belt. The sampling targets of this study are crystalline exotic boulders found within the sedimentary sequences of the Outer Carpathians. They likely represent Proto-Carpathian basement, which was exposed and eroded during the Mesozoic and Cenozoic evolution of the Western Carpathian basin. The majority of the boulders were derived from the Silesian Ridge, which separated the Magura Basin and the Silesian Domains, and which became a source region during Late Cretaceous to Early Paleocene tectonism. Felsic crystalline clasts within the Silesian Nappe yield U–Pb zircon magmatic protolith ages of 603.7 ± 3.8 Ma and 617.5 ± 5.2 Ma while felsic crystalline clasts within the Subsilesian Nappe yield an age of 565.9 ± 3.1 Ma and thus represent different magmatic cycles. The U–Pb zircon data also imply that the Silesian Ridge was likely a fragment of the eastern part of the Brunovistulia microcontinent. The presence of inherited zircon cores dated at 1.3 to 1.7 Ga impply a Baltican provenance. We infer that the Protocarpathian continent represent a long-living magmatic arc, which formed during prolonged Timmanian/Baikalian rather than Panafrican/Cadomian orogeneses.

Mafic exotic blocks, found within the Magura Nappe, yield U–Pb zircon ages of 613.3 ± 2.6 Ma and 614.6 ± 2.5 Ma and likely represent a fragment of an obducted ophiolitic sequence. The protolith of these mafic boulders could represent a Paleoasian Ocean floor, obducted during later orogenic processes and incorporated into the accretionary prism. All analysed exotic clasts show no evidence for younger (Variscan) reworking, which is characteristic of both the western Brunovistulia and the Central Western Carpathians. The Silesian Basin and Subsilesian realm thus had a likely source area in the eastern part of Brunovistulia, while the source of the Magura Basin was the Fore-Magura Ridge, whose basement potentially represents an accretionary prism on the margin of the East European Craton.

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The Silesian Ridge in Carpathian Tethys: its origin and evolution

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The paleogeographic configuration of the Carpathian Tethys changed during its evolution. It consisted of more or less individual basinal units, which arrangement and configuration evolved during Jurassic–Neogene times. These basins were separated by several ridges including the Silesian Ridge, a crucial structure that functioned over one hundred million years during Late Jurassic – Eocene times and played an important role in Outer Carpathian paleogeography. This ridge was destroyed during the orogenic process and presently is represented by clasts eroded from ridge structure and incorporated into the sedimentary cover of the Outer Carpathian basins. The study of this clasts allow to reconstruct the Silesian Ridge evolution. The ridge origin and uplift caused changes in the basinal distribution as well as impacted and controlled the sedimentary processes in surrounding areas.

The Alpine Tethys originated during Early – Middle Jurassic times. It was flanked to the north by North European Platform with Precambrian basement and Paleozoic–Mesozoic sedimentary cover. The back-arc, rift-related Protosilesian–Ceahlau–Severin Basin developed within this platform. The Silesian Ridge constituted a fragment of the North European Platform rifted away during the opening of this basin in Late Jurassic. This ridge separated the wide northern Alpine Tethys and relatively narrow, elongated Protosilesian Basin in the Western Outer Carpathians. The sediments of this part of Alpine Tethys belong now to Magura Nappe while sediments of the Protosilesian Basin belong to Silesian, Subsilesian and Skole nappes of Outer Carpathians. The southeastern prolongation the Protosilesian Basin (the Ceahlau-Severin part), which has oceanic character, marked by ophiolite presence, form several nappes in Eastern and Southern Carpathians on Ukraine and Romania. The Western Outer Carpathian Protosilesian Basin evolved into Silesian Basin, Subsilesian sedimentary area and Skole basins during Late Cretaceous and Early Paleogene times. The Silesian Ridge achieved the maximum uplift and was very active delivering huge amount of clastic material to adjacent basins mainly to the northern one (Silesian Basin). It was a one of the basic source areas of clastic material for thick sandy and sandy-conglomerate complexes (Godula, Istebna, Ciężkowice formations) up to five kilometers in total thickness. It also delivered clastic material to 900 m thick Hieroglyphic Fm. of the Dukla Basin situated between Magura and Silesian basins. The activity of the Silesian Ridge was periodic, the dynamic turbiditic sedimentation was interrupted by deposition of hemipelagic shale complexes during periods of limited supply of clastics. During sedimentation of the Istebna Formation (Late Cretaceous – Early Paleocene) the ridge erosion reached maximum affecting the Precambrian (Brunovistulicum) basement. Large amount of magmatic and metamorphic rocks were delivered to the surrounding basins. The Paleocene – Eocene Outer Carpathian activity form the huge accretionary prism that moved northward, reaching the Silesian Ridge during late Eocene times. Finally, the accretionary prism overridden the Silesian Ridge, causing its destruction during late Eocene – Oligocene times. The large amount of clastic material that incorporates huge olistoliths obtained from the Silesian Ridge were delivered to the newly formed Krosno Basin.

Acknowledgements
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Methodology for creating and visualization of 3D models for mineral deposits of critical EU commodities

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This contribution focuses on research within the project TE02000029 Competence Centre for Effective and Ecological Mining of Mineral Resources, granted by the Technology Agency of the Czech Republic. The main goal of this project is revision of the deposits of selected non-energetic raw materials, which belong to critical EU commodities [https://www.hgf.vsb.cz/ceemir/en/]. Its Work Package WP4 "Spatial modeling of mineral deposits" focuses on digital modeling of selected deposits, using appropriate mathematical techniques, based on the study and evaluation of the archived data. Within this Work Package 3D models of deposits were made: Li–Sn–W deposit Cinovec east (Staněk et al. 2017a), kaolin deposit Jimlíkov-east (located in the neighborhood of the village Jimlíkov, about 5 km west of Karlovy Vary) (Staněk et al. 2017b, Staněk et al. 2017c) and graphite deposit Český Krumlov – Městský vrch (Staněk et al. 2017d).

In this contribution we describe individual steps for creation and visualization of 3D models of the deposit, including all steps from reevaluation of all accessible archived materials and verification and correction of the input data, up to the visualization of categories of the blocks of reserves. Using a specialized software we check all input data, compatibility of used software, and generate outputs: estimates of the deposit reserves in a textual form and various types of visualization of the deposit in 2D and 3D, respectively. This methodology and a newly developed software allow us to both create variant models of the kaolin deposits of this and a similar types and fast updates of the models when the input data and/or the parameters of the model are updated and/or amended. Our dynamic complex model for kaolin deposits can be updated when needed, based on mining explorations including variant estimates of the resources based on a priori defined utility conditions.

In our structure modeling software MOVE [https://www.mve.com/software] standard software tools, standard software such as MS Excel, Surfer [http://www.goldensoftware.com/products/surfer/features] and Voxler [http: //www.goldensoftware.com/products/voxler/features] made by the Golden Software Company, and an open-source software SGeMS (Remy et al. 2009), are used. For creating macros in the MS Office environment we used the Visual Basic for Applications (VBA), while for individual software tools we used the standard Visual Basic.

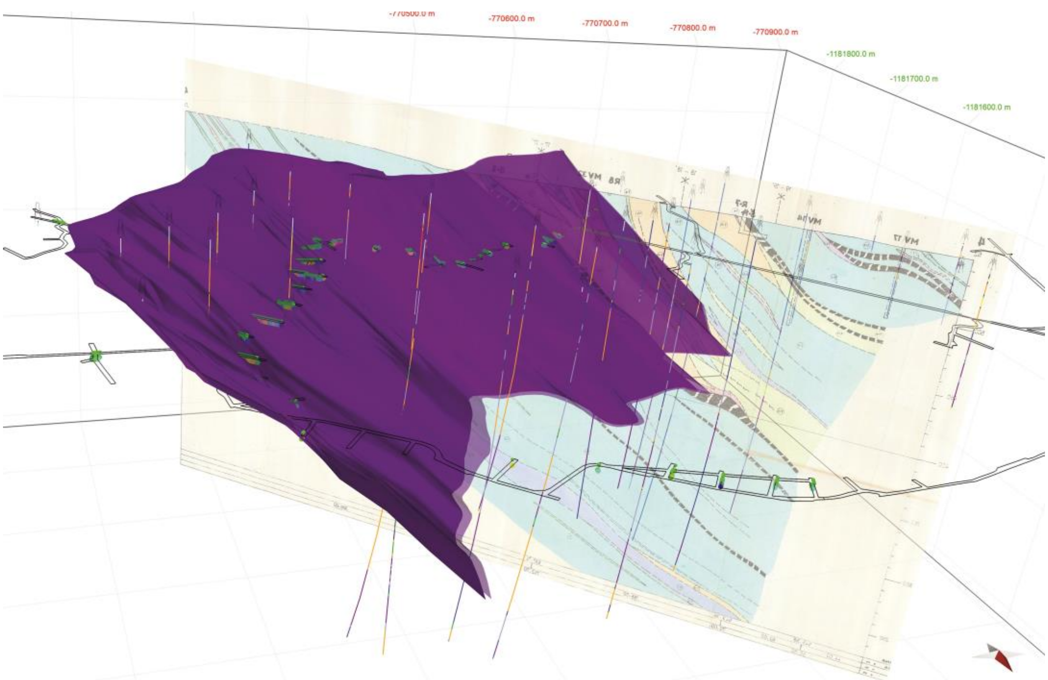

Fig. 1. 3D visualization of the modeled graphite body (purple surfaces) with input data: drilling logs, geological sections (one example), channel sampling sites (colored points in mine workings).

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Geophysical constraints for the tectonic reconstruction of the Chinese Altai

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The potential field data analyses combined with the geology provide a comprehensive geodynamic reconstruction of the Chinese Altai. In order to detect significant crustal structures and estimate their continuity in depth, location and trend of major gradients are determined from spectral and multi-scale edge analyses, pseudo-gravity and tilt derivative transformations. The magnetic lineaments are mainly NW–SE oriented and parallel to the Permian deformation zone which affects a large part of the western and southern Central Asian Orogenic Belt. The NE–SW oriented gravity anomaly lineaments coincide with the Late Devonian – Early Carboniferous deformation fabrics characterized by NE–SW trending upright folds and crustal scale domes. Magnetic and gravity data reveal that the Erqis system is probably not a suture zone between the Chinese Altai and Junggar plates as no prominent deep-seated discontinuity can be identified. Moreover, the geophysical domains are not interpreted as terranes but rather as distinct orogenic crustal levels characterized by different metamorphic grade, structural patterns and spatial extent of magmatic bodies. Instead, the geophysical heterogeneity of the Chinese Altai crust results from the Devonian and Permian tectonometamorphic and magmatic reworking and crustal differentiation of Cambro-Ordovician accretionary wedge. Based on these results, we propose a tectonic model which explains massive crustal thinning and melting of juvenile crust of the accretionary wedge followed by NW–SE Late Devonian shortening and crustal scale doming. The orthogonal Permian collision led to a major crustal scale folding and exhumation of granulites, and partially molten crust along the collisional front in the southern Chinese Altai.

Timescale of pervasive melt migration in the 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 year, 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.

Structural inheritance vs. poly-phase folding: the effect of pre-existing normal faults on the formation of oblique compressional transfer zones – field and 3D seismic examples from the western Transdanubian Range (West Hungary)

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Compressional transfer zones link areas characterized by different amount of shortening (Moustafa and Khalil 2016). Transfer zones are oblique or lateral to the general trend of thrust and fold belt, and they are represented by curved thrusts, oblique and lateral ramps or tear faults.

The study area is part of the Transdanubian Range (TR), a morphologic–tectonic unit of the east Alpine orogeny. The TR is built up by Variscan low grade metamorphic shales and Permian to Cenozoic non-metamorphic succession. The present study introduces the effect of Norian–Jurassic normal faults (Héja et al. 2018) on Aptian–Coniacian folding and thrusting (Fodor et al 2017).

The general trend of compressional structures is N–S in the study area, however, deviations in the trend of folds and thrusts were observed based on seismic and field data. Different directions of fold axes are traditionally explained by multi-phase folding in the TR (e.g, Tari 1994). In contrast, our study shows that, deviations of fold trends occur only in the vicinity of map-scale pre-existing normal faults. Therefore deviations of fold trends can be explained rather by inheritance of Triassic and Jurassic pre-orogenic normal faults; the interaction of early normal and late reverse faults resulted in variable fold axes orientation.

According to the classification of Marshak (2004) oblique or lateral compressional structures influenced by pre-exisiting normal faults can evolve as an initially oblique or lateral structure (oblique or lateral ramps s. s. or non-rotational salient); or due to dragging and rotation of an initially straight structure (rotational salient).

We found that, both of Marschak's (2004) end-member models are responsible for the formation of observed oblique trending folds and thrusts.

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The exsolutions of two plagioclases in the magmatic labradorite, evidence from the coronitic metagabbro from the west of the Teplá-Barrandian Unit, Bohemian Massif

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Coronitic metagabbros occur as small isolated bodies located along the contact between Mariánské Lázně and Teplá Crystalline Complexes (NW of the Bohemian Massif). Their magmatic protoliths intruded into surrounding rocks during Cambrian rifting event about 500 My ago, the whole area subsequently underwent metamorphic overprint during Variscan deformation reaching amphibolite facies conditions (up to 711°C; 13.6 kbar). The magmatic mineral assemblages involve orthopyroxene, clinopyroxene, plagioclase, ilmenite, amphibole and occasionally olivine and biotite. The metamorphic overprint of the gabbros is manifested by 1) formation of multilayer coronas mostly at the contact of plagioclase with various magmatic mafic minerals (clinopyroxene, olivine, orthopyroxene, ilmenite), the newly formed metamorphic phases involve orthopyroxene, amphibole and garnet; 2) specific and complex breakdown of magmatic plagioclase, which is the subject of this study. The studied metagabbro samples contain magmatic plagioclase forming large grains of up to 3 mm size, which usually preserve original labradorite composition in central parts. These grains are then to variable degree replaced by domains occurring at their marginal parts, where the original grain is replaced by a mixture formed by thin elongated lamellae of anorthite-bytownite with apparent random shape orientation in oligoclase-andesine matrix. The same domains often contain spinel grains and corundum lamellae. Spinel forms small (0.2–2 μm) grains and it occurs in different textural positions. Commonly, it is observed as isolated grains randomly distributed within the domain, in some places it forms chain-like texture. Occasionally, spinel grains occur in association with corundum or anorthite lamellae. Corundum is observed in all domains as tabular grains with thickness bellow 1 μm and their distribution exhibits well visible preferred orientation presumably controlled by crystallographic properties of the host plagioclase. 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. The results of the EBSD analyses revealed that all the observed plagioclases have the same crystallographic orientation, i.e. the newly formed anorthite with oligoclase have identical crystal lattice orientation, which is apparently inherited from the parent magmatic labradorite. While the mechanism of this breakdown is not yet clearly understood, it seems to represent some kind of exsolution process. This process possibly started during the metamorphic overprint, when the PT conditions were lower than necessary for the labradorite stability and the breakdown was initiated due to an immiscibility gap in the plagioclase composition. The crystal lattice orientation of the corundum lamellae is restricted and apparently controlled by the crystallographic orientation of the host plagioclase, while the spinel grains don't show any crystal preferred orientation. 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. While the corundum shows some crystallographic relation to the host plagioclase and its precipitation may be viewed as exsolution, the spinel was possibly formed later and its precipitation was already not controlled by the plagioclase crystal lattice.

Cone-in-cone structures: Crack-sealing or continuous vein growth?

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Cone-in-cone structures are common worldwide in sedimentary basins within bedding-parallel veins composed of fibrous crystals (known as beef) in low-permeability rocks (mudstone, evaporite, less often carbonate; Cobbold et al. 2013 and references therein). Cone-in-cone structures are made up of concentric, interbedded cones of wall rock inclusions with fibrous crystals between them. Inclusion bands shape surfaces of solid (or fluid) inclusions arranged parallel to the vein-wall interface, while inclusion trails are aggregates of solid (or fluid) inclusions, which occur oblique to the walls of the vein. There are two preferred mechanism for the formation of these microstructures: crack-seal mechanism and continuous vein opening with simultaneous cementation.

A unique vein generation was observed in drill core samples of the Late Permian Boda Claystone Formation (Mecsek Mts., SW Hungary). The main vein mineral is calcite, in smaller quantities albite, baryte–celestine, anhydrite, chlorite and pyrite can also be observed, both with euhedral and space-filling texture. The veins contain high amount of solid inclusions, which usually have folded, sinusoidal, elongated shape (Fig. 1A). The wall rock clasts appear commonly in unique arrangements as inclusion trails, as inclusion bands and as cone-in-cone structures as well (Fig. 1B). In each case, these structures consist of regularly spaced wall rock fragments. In some cases, the clasts split off just partially from the vein walls and they fold slightly towards the central part of the vein (Fig. 1A).

As none of the classic blocky, elongate blocky, fibrous or stretched crystal morphology can be observed, the microscopic morphology does not reflect the growth mechanism of the veins, only the shape and arrangement of clasts inside the veins can be used.

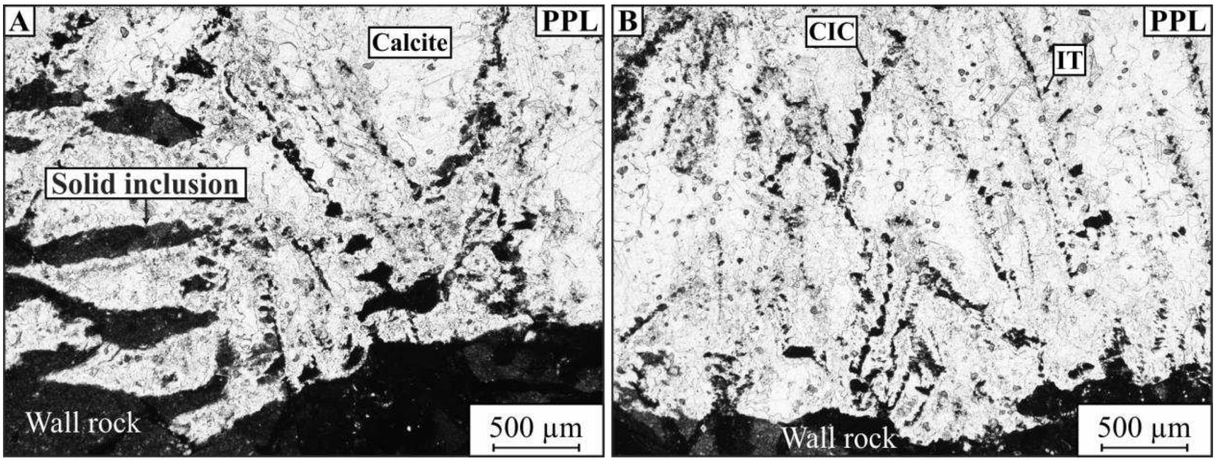

Fig. 1. The geometry (A) and arrangement (B) of solid inclusions within veins from the Boda Claystone Formation. CIC – cone-in-cone structure; IT – inclusion trail.

The main questions are whether there was a role of crack-seal mechanism (Ramsay 1980) or force of crystallization (Means and Li 2001, Wiltschko and Morse 2001) in the generation of this vein generation or not, and most importantly do these veins represent tectonic or diagenetic processes?

The relative position to the vein walls, the folded, sinusoidal geometry and the unique arrangement of the clasts suggest a continuous vein growth mechanism within poorly consolidated sediment. The observable crystal morphologies are probably the results of diagenetic recrystallization of the original fibrous material (Franks 1969).

Acknowledgments

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Permian alkaline magmatism of the SW Mongolia – case study from the balloon-like Aaj Bogd composite pluton

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The Trans-Altai domain of Central Asian Orogenic Belt (CAOB) exposed in SW Mongolia represents oceanic terrain with dominantly exposed Devonian–Carboniferous oceanic sediments and wide spectrum of Carboniferous igneous rocks developed in volcanic-arc environment (Nguyen et al. 2018). This sequence was intruded by numerous post-tectonic Carboniferous–Permian oval-shaped plutons. The largest of them is the 21 × 27 km Aaj Bogd Pluton, exposed in the mountain range N of Altai soum, close to the Chinese border. This zoned pluton intruded into Devonian–Carboniferous flysh. It is dominantly built by biotite–amphibole syenites to biotite leucogranites. In the core of the pluton, monzodiorites–monzogabbros are exposed. Magma mingling textures are developed between acid and basic rocks. Concentric structure of the pluton is accentuated by thin circularly aligned septa of wall rocks (hornfelses, greywackes and siltstones).

Leucogranite (PH057) (samples were classified after Debon – Le Fort 1983) is a medium-grained rock composed of quartz, feldspars and biotite. K-feldspars are indistinctively perthitic. Plagioclases have normal magmatic zoning with andesine cores and oligoclase rims. Albitic rims grow at the contact with K-feldspars, common are myrmekites. Apatite, ilmenite, magnetite and zircon are accesoric.

Syenite (PH062) is composed of quartz, K-feldspar, oligoclase, biotite and tschermakitic amphibole, the latter often decomposed to a mixture of titanite, magnetite, zircon, chlorite and K-feldspar. The syenite yielded originally automorphic, fragmented short prismatic zircon grains. Most of them show oscillatory zoning in core with conspicuous rims up to 50 µm thick. U–Pb ratios measured using LA–ICP-MS gave the lower intercept of 280.9 ± 1.0 Ma, interpreted as the magmatic age.

Monzogabbro (PH055, PH056A) are coarse-grained, formed by olivine (forsterite), pyroxene, plagioclase (labradorite–bytownite) and biotite. Pyroxene crystals are zoned with orthopyroxene ferrosilite in the rims and clinopyroxene diopside in the cores. Ferroactinolite is a product of pyroxene decomposition. Magnetite, ilmenite, long-prismatic apatite and pyrite are accessoric. Zircon grains separated from sample PH056A are hypautomorphic, columnar, with thick lamellae zoning, the majority of concordant ages cluster at 284.7 ± 0.7 Ma. Zircons from the monzogabbro PH055 show similar morphological and zoning features; dominant $^{238}U/^{206}Pb$ ages span 273–300 Ma; two grains yielded older ages of 346.9 ± 5.3, resp. 392.3 ± 6.2 Ma.

Wall rocks of the intrusion are represented by massive hornfelses composed of quartz, plagioclase (andesine–labradorite), locally almandine garnet and cordierite–sekaninaite. The cordierite is often decomposed to biotite, quartz and clay minerals, rarely muscovite. Sillimanite is only exceptionally present. The conditions of the thermal metamorphism were calculated using Thermocalc software to 740 ± 69°C and 2.5 ± 1 kbar, corresponding to an intrusion depth of c. 10 km.

Acid rocks (64 resp. 73 wt. % SiO_2) are shoshonitic and basic rocks (SiO_2 ~ 52 wt. %) high-K calc-alkaline in plot of Peccerillo and Taylor (1976). NMORB-normalized (Sun – McDonough 1989) spiderplots for all samples are expressively enriched in Cs, Rb, Ba, K, Pb and lightly in Zr and Hf; monzogabbros show high Th and U in addition. Characteristic are negative anomalies in Nb, Ta and Ti, and for acid rocks also of Th, U, P and Ti. Chondrite-normalized (Boynton 1984) REE distribution in the monzogabbros and granite is relatively homogenous, with subparallel, slightly concave-down patterns lacking Eu anomaly. Exception represents syenite with a striking positive anomaly (Eu/Eu* = 1.97).

Aaj Bogd is a composite granite–syenite pluton with monzogabbros in the centre. Oval shape and concentric arrangement of host-rock septa indicate ballooning as the main emplacement mechanism. This early Permian pluton intruded in the shallow crust level represented by Upper Palaeozoic accretion wedge in the extensional tectonic regime. While the arc-alike geochemistry of the acid rocks is inherited from the arc-related source, the basic rocks correctly point to a within-plate geotectonic setting which could have corresponded to a developing rift (Yarmolyuk et al. 2008).

Acknowledgements
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Variation and origin of magnetic fabrics in some serpentinized peridotites and eclogites from the Bohemian Massif

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Serpentinized peridotites with lenses of eclogites are usually considered as product of high-pressure metamorphism and subsequent retrogression and deformation during exhumation. The changes of mineral fabrics that occurred during these processes can be documented by some physical properties of rocks (density, magnetic susceptibility and its anisotropy). Density and bulk susceptibility indicate compositional changes, while the anisotropy of magnetic susceptibility (AMS) may indicate structural changes.

The maximum Theoretical Paramagnetic Susceptibility (MTPS) is determined from the Fe and Mn contents assuming that both these elements occur in paramagnetic mafic silicates. In eclogite and peridotite, the MTPS varies from about 5×10^{-4} to about 3.5×10^{-3} [SI]. From literature data, the bulk susceptibility of unaltered eclogite or peridotite is in the upper part of the order of 10^{-4} and in the lower part of the order of 10^{-3}. Consequently, the susceptibility of unaltered eclogite and peridotite is carried dominantly by paramagnetic mafic silicates even though sub-ordinate effects of the Fe–Ti oxides cannot be excluded. If these rocks are altered (serpentinization in peridotites, amphibolization in eclogites), their susceptibility may an-order-of-magnitude increase. This is the case of peridotites and eclogites of the Bohemian Massif the susceptibility of which may reach the order of 10^{-1}. Then, the magnetic fabric of weakly magnetic peridotites and eclogites is controlled by paramagnetic mafic silicates, while in strongly magnetic ones it is controlled by neo-formed magnetite-like spinel minerals.

The magnetic fabrics in some ultramafic bodies were found very different from those of host granulites even though both the rock types experienced common structural history during granulite facies metamorphism. The componental movements forming the granulite fabric were evidently not strong enough to overprint the magnetic fabric of ultramafic rocks, which therefore had sufficient mechanical strength to maintain their pre-granulite facies fabric. On the other hand, there are ultramafic bodies that suffered strong serpentinization and show their magnetic fabric very similar to that of host rocks. This indicates that after their weakening due to serpentinization the ultramafic bodies were susceptible for componental movements due to crustal deformation.

In weakly magnetic eclogites, the magnetic fabric is conformable to the mesoscopic fabric defined by preferably oriented mafic silicates, while in strongly magnetic specimens these two fabrics may differ moderately up to strongly. It is likely that eclogites are relatively susceptible to multiple ductile deformations probably associated with rock exhumation during which neoformation of some minerals took place.

In some peridotites and eclogites, pyrrhotite was found. Its magnetic fabric was investigated through measuring the out-of-phase component of the AMS. It was found that the whole-rock magnetic fabric and the pyrrhotite magnetic sub-fabric are coaxial. It is likely that both the fabrics originated during one and the same process. We believe that this process was creation of peridotites and/or eclogites in the uppermost mantle and/or lowermost crust.

Chromian spinels from the Palaeozoic ophiolitic rock complex of the Zlatník Group (Gemeric Superunit, Western Carpathians): composition, alteration and source rocks

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Chromian spinels are considered as important petrogenetic indicator. In orogenic belts they denote presence of ophiolites or primitive rocks of mantle origin. Chromian spinels which are subject of our study are related to Variscan ophiolite rock complex building up the newly defined the Zlatník Group located in the Western Carpathians near the northern border of the Gemeric Superunit.

The Devonian/Lower Carboniferous Zlatník Group forms a belt of dismembered incomplete multi-stage metamophosed ophiolites and related rocks representing a part of the former Variscan ophiolite suture. Lower part of the Zlatník Group denoted as the Závistlivec Fm. is composed of ophiolite mélange. This mélange contains blocks, enclaves and clasts of metabasalts, metadolerites, metagabbros, metaultramafics and rarely also acid differentiates embedded in metamorphosed sedimentary matrix mostly of pelitic or psammitic granularity, although layers of sedimentary breccias have been also found (Ivan – Méres 2012).

Chromian spinel as accessory component has been found in the three different rock types: (1) in the hydrothermally altered ultramafic rocks (listvenites), (2) in the metamorphosed olivine gabbro and (3) in the metamorphosed sandstones to microconglomerates. Only chromian spinels from talc-carbonate rocks – a less altered variety of listvenites – have been studied. In these rocks chromian spinels form individual, originally euhedral grains up to 3 mm in diameter, more or less cataclased and variously affected by metamorphic transformations. Primary magmatic brown spinel is still preserved in some samples but usually is transformed from periphery and along cracks to opaque compact form or is affected by further alteration to the porous variety with numerous inclusions of chlorite. Chlorite aureole can be also evolved around the latest mentioned type. More intensive alteration left after original spinel grain only aggregate of chlorite with cluster of magnetite grains in its centre. Chromian spinel in the metamorphosed olivine gabbro form small (no more than 0.2 mm in size) euhedral crystals, compact or partly porous, which are also partly replaced by fuchsite aureole and rimmed by small (0.05 mm) columnar crystals of Cr-pumpellyite. Detrital chromian spinel as relatively widespread accessory mineral is present in some metamorphosed psammitic clastic sediments belonging to mélange matrix. Their types are practically identical with those from talc-carbonate listvenites only with one difference – they are rimmed by fuchsite aureole which fully or partly replaced original chlorite aureole. Sediment itself contains rock and mineral clasts indicated mixed ophiolite and arc volcanic material source.

Compositional variability of chromian spinel in the talc-carbonate listvenites is almost identical with that observed in detrital spinels from metapsamitic sediments. The best preserved brown spinels forming usually cores of grains fall in the classification diagram $Y(Fe^{3+})$–$Y(Cr^{3+})$–$Y(Al^{3+})$ into fields of picotite and Al-chromite. High content of MgO (10.08 – 13.56 %) and low contents of TiO_2 (0.00–0.06 %), MnO (0.22–0.39 %) and ZnO (0.10–0.20 %) are typical. This type of chromian spinel is altered gradually to compositions with the same aluminium content (boundary of Al chromite/chromite in classification diagram), but lower MgO content (9.64–6.76) and slightly higher ZnO, MnO and TiO_2 contents. Porous (locally also compact) chromian spinel forms chemically distinct, always clearly defined external rims of various thickness progressively replaced previously mentioned spinel composition. In classification diagram it is plotted in the fields of chromite and ferritchromite. Very low concentrations MgO (< 1 %), increased concentration ZnO (up to 5.72 %) and rarely also MnO (up to 3.11 %) are typical. Best preserved chromian spinels from metagabbro display at the same aluminium concentration level much less magnesium content (2.30–4.40 % MgO) but more TiO_2 (0.40–0.50 %). No differences in compositional trends related to their alteration are observable in comparison to spinels from the other studied rocks. Composition of best preserved chromian spinels indicates that they were formed by magmatic processes in ultramafic rocks probably related to the typical oceanic depleted mantle lithosphere. The same type of rocks is supposed to be a source of detrital spinels in the metapsammites. Metamorphic alteration of chromian spinels is probably related to exhumation of oceanic ultramafic rocks and subsequent serpentinization. Overprinting by further metamorphic processes led finally to their transformation up to magnetite, Cr-chlorite or fuchsite.

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Spectral parameters of microdiamonds from north Bohemian Saxothuringian basement

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Microdiamonds reaching 10–30 microns in size are enclosed in kyanite, garnet and zircon within two types of the ultra-high-pressure rocks (acid and intermediate, with mineral assemblage garnet–kyanite–feldspar–quartz and garnet–clinopyroxene–feldspar–quartz, respectively) both from boreholes and outcrops in the north Bohemian Saxothuringian basement (Kotková et al. 2011). Microdiamonds are well-preserved without graphite coating. We focused on spectral parameters of microdiamonds, located under the surface of the thin-section within various host phases, as a reflection of microdiamond structure and stress state, the latter potentially constraining the exhumation path.

Single octahedral microdiamonds in the acid UHP rock exhibit perfect to slightly distorted crystals with sharp edges, closed and straight boundaries towards the host phase, and rare resorption and growth features on crystal faces. The position of the first-order Raman band of the diamond octahedra varies mostly between 1332.1 cm^{-1} and 1334.4 cm^{-1} (1336.7 cm^{-1} at maximum), plotting in the up-shift region in Fig. 1. FWHM (full width at half band-maximum) shows a narrow range of 6.3–7.8 (10 at maximum). The Raman spectral parameters do not change with diamond morphology (i.e. perfect octahedra vs. elongated, distorted grains, all enclosed in kyanite).

Cuboid microdiamonds in the intermediate UHP rock occur both as individual grains and clusters and can be monocrystalline or polycrystalline. They show irregular boundaries towards the host phase and cavities and gaps at the diamond-host interface. Resorption and growth features are common. The Raman shift of cuboid diamonds under the surface (1331.2 cm^{-1}–1334.4 cm^{-1}) extends to the down-shift region in Fig. 1, and FWHM range (2.8–8.0) is large compared to diamond octahedra from the acid UHP rock. Both the down-shift and variable FWHM up to relatively high values are characteristic of diamond enclosed in zircon, whereas diamond within garnet features both up-shift and down-shift at lower and less variable FWHM. Raman spectral parameters do not depend on the diamond grain character (individual monocrystal, monocrystal in clusters, cuboid vs. elongated grain). The contrasting values and range of FWHM for the two distinct diamond morphologies relate to their variable crystallinity, FWHM of c. 6–8 for octahedral diamond being typical of these well-crystallized monocrystalline microdiamonds (comp. 1.6 for macroscopic diamonds (Solin and Ramdas 1970). Based on experimental data, which constrain pressure dependence of the first-order Raman band in diamond (Hanfland and Syassen 1985), the microdiamonds exhibit residual overpressure of 0.8 GPa (up-shift of 1334.4 cm^{-1}). However, according to the theory of elasticity and to a concept of isomeke, diamond enclosed in garnet should develop underpressure on exhumation as a result of the differences between the thermo-elastic properties of the diamond and garnet. A viable explanation of the documented overpressure is elastic resetting of diamond at high temperature and lower pressure (Angel et al. 2015). This is in agreement with the "hot", adiabatic exhumation P–T path reconstructed for the UHP rocks based on thermodynamic modelling (Haifler and Kotková 2016).

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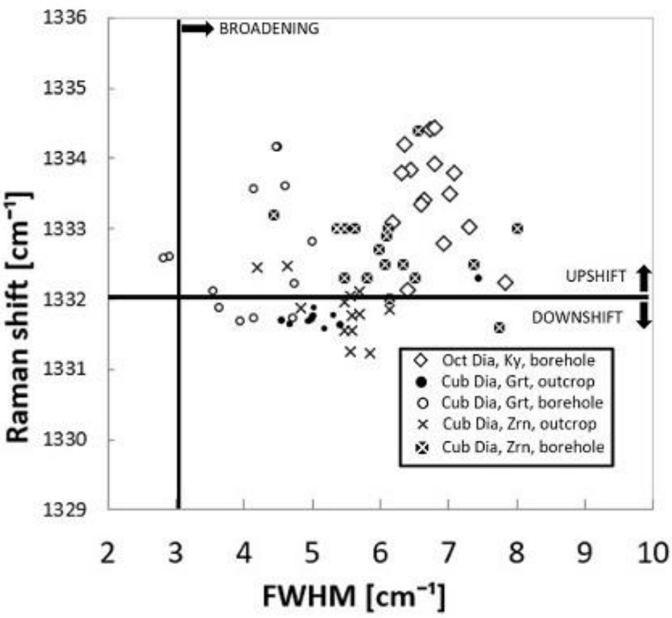

Fig. 1. Spectral parameters of microdiamonds from north Bohemian Saxothuringian basement.

Evidence for post diagenetic NW–SE horizontal compression as documented by stylolites, Prague Synform (Barrandian)

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This paper focuses on the pressure solution structures (stylolites) in the lower Paleozoic limestones in the Prague Synform (Teplá-Barrandian Unit). The Prague Synform is a deformed relic of the sedimentary basin that developed during Ordovician to middle Devonian. Onset of the Variscan deformation is documented by sedimentation of the clastics of the Srbsko Fm.

Our detailed study on stylolites was done on more than 20 localities in the area between the Beroun and the Prague. One of interested features of the area is abundant presence of structure with character between clevage and stylolite. This structure was formed during compression, when spaced cleavage forms mainly by pressure solution, aided by elevated temperatures and pressures caused by overburden as documented by presence of quartz and calcite crystals with petroleum inclusions in the calcite filled extensional zones that documents migration of hydrocarbon during thrust faulting (Suchý et al. 2000).

After unfolding two distinct groups of stylolites were recognized: first one is represented by stylolite teeths that are oriented aproximately perpendicular to bedding, and the second one with bedding parallel stylolite teeths that forms girdle oriented S–ESE with average to the southeast. Poles of fold axial planes are oriented to southeast like the bedding parallel stylolite teeths, documenting the same orientation of compresional stress. Cleavage develops before and during the folding as is documented by passive stylolite reorientation in folds. Stylolite teeths that are perpendicular to the bedding are less common and they are probably of the diagenetic origin. Bedding parallel stylolite teeths were created during horizontal compression that caused thrusting and folding of the Lower Paleozoic in the Prague Synform (Melichar 2004).

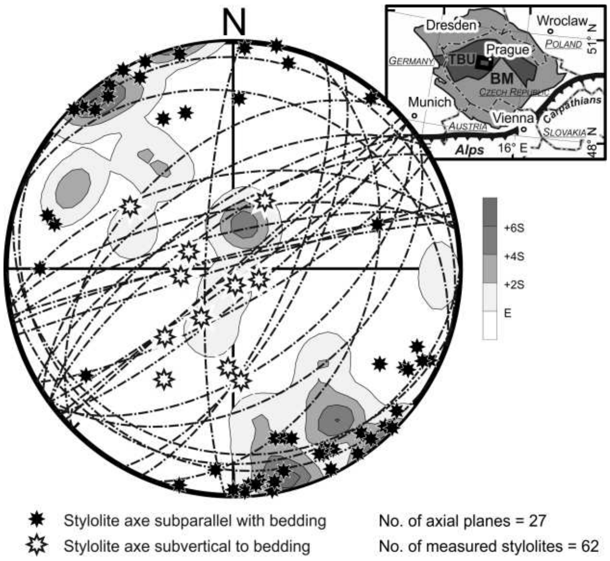

Fig. 1. Equal area stereogram of measured fold axial planes (dot-and-dash line) and unfolded orientation of the stylolites columns (stars). Data from localities in the Prague Synform (near Karlštejn, Radotín, Prague - Barrande's rock).
Small map: Grey: outline of the Bohemian Massif (BM), Dark grey: position of the Teplá-Barrandian Unit (TBU), dark line with triangles: Alpine Front.

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(Ultra-) potassic plutonism – 'the finest hour' of the Variscan Orogeny in western–central Europe

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Deeply dissected ancient orogens are highly promising for studies of crust–mantle interactions, often leading to generation of (ultra-) potassic magmas. (Ultra-) potassic syenite–(mela-) granite plutons and Mg–K-rich products of their differentiation, with countless lamprophyre/lamproite dykes, occur in the Moldanubian Zone of western–central European Variscides (French Massif Central, central–southern Vosges, Schwarzwald, Bohemian Massif, Alps and Corsica). Many of these plutons were dated at c. 340–335 Ma, suggesting a near-synchronous melting of enriched subcontinental mantle along the orogenic belt (von Raumer et al. 2014). Three illustrative examples are given below.

In the French Massif Central, mafic, potassic magmas – vaugnerites – resulted from melting of a phlogopite-bearing mantle (Couzinié et al. 2014, 2016; Moyen et al. 2017). The vaugnerite suite was diachronous, dated to c. 335 Ma in the northerly Forez and Morvan areas, and to c. 310 Ma in the southerly Cévennes. A second peak of vaugneritic activity in the entire area occurred at c. 305 Ma, the age of the Velay anatectic Complex (Laurent et al. 2017).

In the Vosges Mts. intruded two c. 345–336 Ma Mg–K magmatic suites: Central (CVMg–K) Amp–Bt syenite (durbachite) to granite emplaced into high-grade metamorphic units and Southern (SVMg–K) represented by mafic rocks and porphyric to fine-grained granites intruding the upper crust (Schaltegger et al. 1996; Tabaud et al. 2015). These two Mg–K groups differ in geochemical signatures – the more radiogenic Sr and less radiogenic Nd of the CVMg–K resembles the Bohemian durbachite suite (Tabaud et al. 2015).

In the Moldanubian Zone of the Bohemian Massif, the ultrapotassic plutons belong mostly to the strongly porphyritic durbachite suite of Amph–Bt qtz syenitic–melagranitic plutons; essentially equigranular Bt–two-Px qtz syenites–melagranites are less voluminous. The ultra-K plutons are associated with large ~340 Ma felsic HP–HT granulite massifs enclosing bodies of mantle peridotites (Janoušek et al. 2004; Kusbach et al. 2015). In the western part of the Moldanubian Zone, durbachitic plutons older than 339 Ma (Knížecí Stolec and Milevsko) were emplaced syntectonically (Verner et al. 2008). The younger, c. 335 Ma intrusive bodies (syenitoid Tábor Pluton and Central Bohemian Dike Swarm) intruded post-tectonically, into the already exhumed and cooled crust (Kubínová et al. 2017). In contrast, the (ultra-)potassic plutons of the eastern Moldanubicum exclusively show syntectonic pattern of magma emplacement, either related with the Brunia underthrusting (e.g. durbachitic Třebíč Pluton) or dextral shearing along its western edge (e.g., syenitoid Jihlava Pluton) (Verner et al. 2006). The development of both bodies was completed by c. 335 Ma (Kotková et al. 2010).

Analogous rock types form dykes in Niemcza Zone in the Góry Sowie Mts. (Leichmann & Gawęda 2002). They contain late-magmatic zircons, dated at 341.8 ± 1.9 Ma (Przedborowa Amp–Bt monzodiorite) and 335.6 ± 2.3 Ma (Koźmice Bt–Cpx monzodiorite) (Pietranik et al. 2013). Melasyenites comparable with durbachites in the Kłodzko – Złoty Stok Pluton are c. 334 Ma old (Jokubauskas et al. 2017).

All these manifestations of broadly contemporaneous (ultra-) potassic magmatism share crustal-like radiogenic isotopic signatures and strong enrichment in lithophile elements such as Cs, Rb, K, Th and U accompanied by high Cr, Ni and Mg contents. This requires an origin from mantle source metasomatized by fluids and/or high-pressure melts derived from subducted mature crustal material (Holub 1997; Becker et al. 1999; Janoušek & Holub 2007; Krmíček et al. 2016; Soder & Romer 2018). Thus the broadly contemporaneous (ultra-) potassic magmatism bears a witness of vigorous interactions between the deeply subducted and relaminated crustal material and the surrounding lithospheric mantle (Janoušek & Holub 2007; Schulmann et al. 2014). Crust-like radiogenic isotope ratios of the (ultra-) potassic magmatic rocks mask such juvenile additions to the crust (Couzinié et al. 2016), and thus require us to reconsider the current models of the crustal growth in the collisional orogens.

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Magnetic fabric of strongly magnetic granite of Anenský Mlýn occurring at E margin of weakly magnetic Western Granodiorite Complex of the Brno Batholith

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The Brno Batholith (term proposed by Leichmann and Höck, 2008), is conventionally divided into 3 parts: (1) Eastern Granitoid Complex, (2) Central Metabasite Zone (showing character of metamorphosed ophiolite sequence), and (3) Western Granitoid Complex. Granitoids (1) are strongly magnetic, mostly with susceptibility 10^{-3} to 10^{-2} [SI], rocks (2) show extremely variable susceptibility ranging from 10^{-5} to 10^{-1}, and granitoids (3) are mostly weakly magnetic with susceptibility 10^{-5} to 10^{-4} (e.g. Hrouda, 1985). Near the E margin of (3), there are bodies of strongly magnetic granite, which was investigated in more detail in the locality (abandoned quarry) of Anenský Mlýn.

The granite is composed of K-feldspar ($Ab_{5–9}$), plagioclase (cores: $An_{20–27}$, rims: $An_{2–8}$), quartz and biotite (mg# = 0.42–0.48). Magnetite, zircon, apatite, allanite, ilmenite (± titanite and rutile) represent common accessories. The rock is typical of elevated concentrations of K, Th and U (Sedláková, 2008; Skála, 2012) with respect to the other rocks of the Brno Batholith and a positive gravimetric anomaly (Leichmann and Höck, 2008). It is also relatively rich in contents of LREE.

Magnetite, mostly associated with biotite and apatite (± allanite, zircon, ilmenite), is the most common Fe-accessory mineral. It forms hypidiomorphic grains, first hundreds of µm (exceptionally up to 500 µm) in size. Its preferred orientation was investigated by the Anisotropy of Magnetic Susceptibility (AMS). The bulk susceptibility ranges from 1 to 24 × 10^{-2}, the degree of AMS is relatively high (P ~ 1.15–1.35), and the magnetic fabric is predominantly linear. The magnetic foliation poles create an irregular moderately plunging girdle oriented NW–SE. The magnetic lineation create a conspicuous cluster moderately plunging NE. The surrounding diorite shows slightly lower susceptibility, mostly 10^{-3}, comparable degree of AMS, and magnetic fabric ranging from moderately planar to moderately linear. The magnetic foliation poles create a narrow cluster moderately plunging W. The magnetic lineation creates a cluster very similar to that in granite, moderately plunging NE. The very similar orientations of magnetic foliations and magnetic lineations in strongly magnetic granite and in less magnetic surrounding diorite indicate that these rock types probably experienced similar structural histories. However, these histories were not identical, which is indicated by slightly differing AMS ellipsoids (linear magnetic fabric in granite, moderately linear to moderately planar magnetic fabric in diorite).

The studied granite shows, due to relatively high content of magnetite, an order-of magnitude higher susceptibility that do the other granitoids of the Western Granitoid Complex. In addition, it is also more radioactive thanks to up to 4 vol. % of allanite (Sedláková, 2008). In contrast to the granitoids of the Eastern Granitoid Complex, where magnetite is at least partially post-magmatic (e.g. Kubeš et al. 2019), the magnetite in the granite investigated seems to be primary in origin.

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New constraints on the tectonometamorphic evolution of the Barrovian-type metasediments surrounding high-grade rocks of Erzgebirge Mts. (Saxothuringian unit, Bohemian Massif)

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In contrast to well-studied and documented high-grade rocks of the Erzgebirge crystalline complex (Saxothuringian unit), the hanging wall medium- to low-grade metamorphic series are scarcely studied, although they well preserved the record of Variscan structural and metamorphic evolution. The relation between the southern high-grade rocks, mostly composed of micaschists and gneisses, and the northern surrounding upper low-grade metasediments, mostly phyllites, is still unclear. Detailed structural investigations accompanied by thermodynamic modelling of critical samples were done along four cross-sections from low-grade to high-grade rocks. Three distinct tectonic and metamorphic events have been identified. The structurally highest low-grade phyllites are affected by a penetrative subhorizontal metamorphic fabric S1. Structurally deeper, towards the transition to mica schists, the foliation S1 is commonly affected by asymmetrical folding with west-dipping axial planes, which is responsible for general steepening of early S1 foliation. Further to the south, the intensity of metamorphism gradually increases and is accompanied by the development of new NW shallowly dipping metamorphic foliation S2. The superposition of two fabrics marked by transposition of S1 into S2 is commonly observed, especially in domains where old fabrics were steeply oriented. Finally, both metamorphic fabrics are heterogeneously affected by a late upright D3 folding with ENE–WSW plunging horizontal fold axes. Petrological studies and thermodynamic modelling show that the early D1–M1 event, responsible for the formation of S1 fabrics, affected all studied rocks and occurred under HP–LT conditions (14–15 kbar, 480°C). In the structurally highest phyllites, the M1 event occurred under slightly lower pressure and higher temperature conditions (12 kbar, 530°C) comparing to deeper garnet-bearing mica schists. The D2–M2 event, responsible for the formation of S2 fabrics, affected only the structurally deeper part of studied sections and occurred under MP–MT conditions (9 kbar, 610–650°C). We are of the opinion that studied rock assemblages represent a part of the early subduction-related accretionary wedge, which was later affected by barrovian-type metamorphism M2 due to significant heating of the deeper part of the crust.

Preliminary paleostress analysis in the quarry Rožmitál at Broumov (Intra-Sudetic Basin, Czech Republic)

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The aim of this contribution is to evaluate paleostress in the quarry Rožmitál situated close to the town Broumov in the Czech part of the Intra-Sudetic Basin. This locality is formed by Permian mafic volcanic rocks (andesites/melaphyres) which have been penetrated to the Olivětín member of the Broumov formation. The volcanic activity in studied area started with phreato-Strombolian and phreatomagmatic eruptions and was followed by effusive activity forming lava domes and flows (Rapprich et al. 2012). The rocks were affected by fault structures with slickensides, striations and conjugate fault pairs as a result of regional extension (Awdankiewicz 2011). Zíma (2016) have been described normal faults in the strike WNW–ESE steeply dipped to SSW.

Paleostress analysis was realized by the program MARK2010 (Kernstocková 2011). This programme processes the heterogeneous data sets of polyphase reactivated faults, the determination of the states of stress and the separation of homogeneous data groups in relevant phases. This application is based on the method of multiple inversion and direct calculation of the reduced stress tensor from the foursome of the faults. This software tool puts to use geometrical properties of any fault expressed as unit vectors in the 9D space. The orientations of both the fault planes and the striations complemented by a sense of slip are constructed by two orthogonal unit vectors and by derived third orthogonal unit vector in the 3D real space. The fault data were plotted in the azimuthal Lambert projection on the lower hemisphere. The input data are the orientations of both the fault plane and striation, the sense of the slip and the angle of internal friction. The chosen angle of internal friction was 32° for volcanites. Error elimination was processed by the orthogonalization. Potential fault reactivation was reduced to the most frequent percent occurrence. This programme determines the trends of principal normal stress $\sigma1$, $\sigma2$ and $\sigma3$ by a search of the 9D space. These trends of principal normal stress must be perpendicular themselves and in a correspondence with the Lode ratio ranging from –1 to 1. States of stress (phases) were distinguished with relevant trends of principal normal stress and Lode ratio. The numerical attribution of the phase of stress does not mark chronological sequence, but it is an order due to a number of solutions from multiple inversion. The tool "separation" enables quantitative classification of individual faults with the given phase of stress. The criteria of phase classification of the faults were: 1) angle difference between the fault vector and the stress tensor vector (ideally 90°), 2) fault frequency (based on multiple inversion from fault foursomes), and 3) homogeneous fault data set. The programme MARK2010 shows the probability of fault reactivation by computed stress. The higher the presumption of activation by the calculated state of stress, the more frequent the fault.

Compass orientations of both the fault plane and striation were measured in 4 sites inside the quarry. Normal faults and sinistral strike-slip faults were determined due to striation and mineral (esp. hematite) growth stages on fault planes. The total of 44 input data of fault planes and striatios were processed by the orthogonalization. The process of separation led to quantitative division of normal faults and one case of the reverse fault at four states of stress (phases). Generally in all the phases, the trend of maximal principal normal stress $\sigma1$ is WNW(NW)–ESE(SE) with gently inclined plunge and Lode ratio reaching from 0.2 to 0.6.

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Kaolinite deposits trapped in karstic sinkholes of planation surface remnants used as paleotectonic, paleoclimate and provenance indicators, Transdanubian Range (Hungary), Pannonian Basin

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In the southwestern part of Transdanubian Range (Keszthely Hills and South Bakony Mountains), there are karstic sinkholes on the planation surface of Triassic carbonates trapping grey clayey-silty kaolinite deposits. The depth of these sinkholes reaches up to 100 m in the South Bakony Mountains and up to 50 m in the Keszthely Hills. However, the latter is strongly eroded (Bohn 1979). The composition and accumulation age of these terrestrial kaolinite deposits were determined by heavy mineral analysis and U–Pb zircon dating. Samples from the Southern Bakony Mountains showed a balanced zircon, rutile, tourmaline dominated heavy mineral spectrum. Their U–Pb data indicate an accumulation period between 20 to 16 Ma. Beside these young components, Archean to Mesozoic ages were also determined and implicating a mixed source. The Keszthely Hills sample consists almost no other heavy mineral species than 17.5 to 14 Ma euhedral zircons, reflecting a major contribution from the Carpathian-Pannonian Neogene volcanism. The shift in the Miocene age components can be explained by the landscape evolution and burial history of the planation surface remnants controlled by the local tectonic activity.

The significant amount of 18 to 19 Ma zircons indicate that the kaolinite formation started earlier in the Southern Bakony Mountains and it is unclear whether they filled up newly formed or paleokarstic features. The absence of these older Miocene components in the Keszthely Hills, despite the high amount and representative measurements, suggests that the kaolinite deposits formed simultaneously with their hosting sinkholes in this area. The 50 m deep morphology and Paleogene nannoplankton content (Bohn 1979) combined with the new geochronological and heavy mineral data indicate that the Keszthely Hills sinkholes formed under the coinciding and preferable warm–humid climate conditions of the Miocene Climatic Optimum on a terrain affected by an active tectonism (Balla 1984, Csontos et al. 1998, Zachos et al. 2004, Schmid 2008, Balázs et al. 2016). The missing younger than 16 Ma components in the South Bakony Mountains indicate that around this time interval the kaolinite deposits were covered here, while in the Keszthely Hills they accumulated materials until 14 Ma.

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Study of geomechanical conditions of magmatic rocks based on drillcore exploration of Cínovec deposit (Bohemian Massif)

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Drill exploration has been ongoing since 2012 in the Cínovec deposit. The core-drilling program has completed more than 30 core boreholes with an average depth of 300–400 m. Relative rock strength of selected drillcores was measured by the Schmidt hammer due to good experience from the previous research (e.g., Knížek et al. 2018). Discontinuities, structural deformations and other alterations were described at the same time.

The Schmidt hammer is mainly used for civil engineering purposes (especially for strength measurement in concrete studies), but it can be also used for geological research. The equipment enables indirect detection of compressive strength by measuring scleroscopic strength (e.g., Aydin – Basu 2005). The ADA 225 device, equivalent to the Schmidt Hammer type N with a kinetic energy of 2,207 J, was used for the tests. This device can measure rock strength above 10 MPa. As the device is not used in a standardized manner and outside of the laboratory, the resulting values are not quantitatively accurate.

The rock strength was growing under the eluvium. The changes of rock strength are reflection of local alterations of rocks and healthy or decomposed rocks. Disability of rocks (tectonic crushing, kaolinization and other alterations, chemical erosions) reduces strength. The research continues.

Correlation of individual joints from the drill cores with the same joint systems from the rock outcrops was possible due to the statistical results of the altitude-dependent inclinations. The joint systems were oriented in two main directions NE–SW and NW–SE, which represent the systems of perforated structures to the Ohře rift. The joints with a subvertical inclinations are significant in the system with main direction NE–SW and the sloping joints are oriented in the second main direction SW–SE.

This analysis can answer questions about geomechanical properties of rocks. The results of this study will be used for possible mining work etc. This approach can also be applied to other localities and it is also useful for other research of applied geology.

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Chemical heterogeneity within a single small serpentinite body and its implications for mantle characterization as observed in the Biskoupky serpentinite, Czech Republic

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The most metasomatized part of the Moldanubian Zone in the Bohemian Massif – the Gföhl Unit – comprises a variety of peridotites that presumably originated from different tectonic environments (Medaris, et al. 1990). Peridotite bodies are hosted mostly by HT–HP felsic rocks (gneiss, granulite). Based on major and trace elements, P–T conditions and cooling rates, three types of peridotites were identified (Medaris et al. 2005), representing (I.) suboceanic lithosphere and asthenosphere, (II.) subcontinental lithosphere, and possible (III.) ultramafic cumulate complexes. We investigated major/trace element compositions and bulk rock Sr–Nd isotope compositions in spinel peridotites from Biskoupky peridotite (8 km^2, district Brno-venkov, Czech Republic), classified by Medaris et al. (2005) as "Type I", i.e. rapidly cooled and equilibrated in low P–T regime, most likely representing suboceanic lithospheric mantle.

Our work takes advantage of a set of samples obtained for an 80 m vertical profile (50 m quarry wall + 30 m borehole). Samples were collected every 5 meters along the profile to avoid sampling bias. Although macroscopically similar, samples vary significantly in major/trace element as well as isotopic compositions. Based on petrological characteristics and major-element compositions samples were characterized either as less serpentinized spinel peridotites (*Group A*) or strongly weathered serpentinized spinel peridotites cut by veins (*Group B*). The *Group A* samples are apparently closer to the protolith composition and thus should better represent the original upper mantle.

Group A (12 samples) is characterised by peridotite-like Fe/Mn wt. ratio 60 ± 10, which is relatively constant among peridotites worldwide. Al_2O_3 (anhydrous) contents between 1.1 and 3.0 wt. % suggest refractory nature of the peridotites. The Ca/Al wt. ratio varies between ~0.6 and 1.2 with the mean around 0.8. The MgO/SiO_2 and Al_2O_3/SiO_2 range from 0.85 to 0.99 and 0.04 to 0.07 and are thus consistent with the field defined for the abyssal peridotites (Niu 2004); the overall trend is parallel to the Terrestrial Array. The LOI value is 9.8–11.5 %, lower than Group 2 samples 11.5–13.5. Samples show nearly flat REE chondrite-normalized patterns with a sum of REE 1.6–4.0 ppm.

Group B peridotites (7 samples) have MgO/SiO_2 ~ 0.81–1.00, i.e. similar to *Group A,* but with lower Al_2O_3/SiO_2 (0.006–0.03). The Fe/Mn ratios are highly heterogeneous. Serpentinized samples give the lowest sum REE (0.4–0.8). Group II samples show strong Eu anomaly, (up to 8.1).

Initial $^{87}Sr/^{86}Sr$ ratios calculated to 340 Ma are only slightly heterogeneous (0.7072 to 0.7082), while ε_{Nd} vary between –2.5 and 3.5.

The evolution of massive peridotites from Biskoupky probably involved a wide spectrum of possible petrogenetic processes: metasomatism, melt–rock interaction, partial melting, serpentinization and low-temperature weathering. Based on major-element composition, which is not affected by serpentinization, we suggest that the mantle protolith of Biskoupky was of abyssal origin. However, contents of fluid-mobile elements (U, Cs, Rb, Ba Pb, Sr and Li), compared to worldwide serpentinites (Deschamps et al. 2013) would apparently indicate a subduction-related history for Biskoupky serpentinized peridotites. Nonetheless, it is open to discussion to what extent this reflects the serpentinization process. Sr–Nd isotope trends suggest possible mixing between sources with slightly contrasting isotopic fingerprints.

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The Miocene granitic rocks of the Central Slovakian Neovolcanic Field: Isotopic constraints

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The Alpine orogeny has produced granitic rocks during the Phanerozoic (Late Cretaceous – Eo-Alpine) and the Cenozoic (Miocene – Late-Alpine) periods in the Western Carpathians. The youngest granitic rocks of the Western Carpathians – Miocene in age – are the focus of this study. The inner parts of the Western Carpathians were affected by extensive volcanism linked to the back arc rifting associated with asthenosphere updoming and/or formation of the Panonnian Basin in the Neogene/Quaternary. Neogene volcanic rocks form the so-called Central Slovakian Neovolcanic Field (CSNF). The diorites and granodiorites belong to the Hodruša–Štiavnica Intrusive Complex (HŠIC) which crops out in the central part of the CSNF and forms a resurgent horst that comprises an older diorite subvolcanic intrusion and a younger granodiorite bell-jar pluton extending over an area of 100 km^2 (Konečný et al. 1983). The diorites and diorite porphyries are medium to coarse-grained, dark grey, massive magmatic rocks with equigranular and porphyric texture. Petrographically, they consist of hypidiomorphic and/or phenocrystic basic plagioclase, orthopyroxene and amphibole, whereas quartz, orthoclase and rarely fine biotite form anhedral crystals and groundmass. Accessory phases include magnetite, apatite and zircon. The majority of the diorite bodies are chloritized or propylitized, often with manifestations of silicification, sericitization and pyritization. Chemistry of diorites of the HŠIC is typical of worldwide diorites. The massive granodiorites consist of intermediate plagioclase, quartz, K-feldspar, biotite, amphibole, and accessory magnetite, titanite, pyroxene, apatite and zircon. Their texture is equigranular and porphyric in marginal parts, locally with mafic microgranular enclaves. The granodioritic rocks are often altered – sericitized, chloritized and propylitized. Their chemistry is similar to other granodiorites and granites from the Western Carpathians, with marginally elevated contents of CaO, FeOt, MgO, Ba, Cr, V and F. The initial $^{87}Sr/^{86}Sr$ ratios have a narrow interval from 0.7066 to 0.7086 although more felsic granodiorites paradoxically have less radiogenic Sr isotopic compositions (0.7066–0.7072) compared with diorites (0.7068–0.7086) which puts serious uncertainty on their comagmatic origin. Generally, Sr isotopic composition suggests a lower crustal source affected by sub-continental lithospheric mantle and an I-type character of the HŠIC granitic rocks. Similarly, Nd isotopic composition with $\varepsilon Nd_{(i)} = -3.7$ to -3.5 for granodiorites and $\varepsilon Nd_{(i)} = -6.0$ to -4.1 for diorites indicates lower crustal source influenced by SCLM for granodiorites, and/or notable crustal assimilation for diorites. Whole rock Hf isotopic data with $\varepsilon Hf_{(i)} = -3.5$ to -2.9 for granodiorites and $\varepsilon Hf_{(i)} = -4.6$ to -3.9, paralleled by zircon Hf isotopic data ($\varepsilon Hf_{(i)} = +1.6$ to $+5.2$ for granodiorites versus $\varepsilon Hf_{(i)} = -3.3$ to $+1.7$ for diorites) appear to require their dual origin. Whole-rock Pb isotopic ratios displaying narrow intervals with $^{206}Pb/^{204}Pb$ = 18.73–18.91; $^{207}Pb/^{204}Pb$ = 15.672–15.677 and $^{208}Pb/^{204}Pb$ = 38.99–39.08 are higher than MORB and lower than common crustal collisional products, implying lower crustal metabasic rock source. Whole-rock oxygen isotope signature with δ18O = 6.1–7.1 ‰ and Li isotope composition (δ7Li = −2.3 to +1.5 ‰, underscored by rather low Li contents of 12–30 ppm) partly overlap in both granitic types and are between common mantle and/or supracrustal rocks, fitting well to continental volcanic rocks. New SHRIMP zircon and ZHe & AHe dating proved the diorite age of 15 Ma, whereas the granodiorites were emplaced before 13 Ma (Kohút − Danišík 2017). The Neogene evolution of the Carpathian-Pannonian area was controlled by gravity-driven subduction of lithosphere under the Outer Carpathians flysch basins with the arc-type magmatism as a consequence of the complex multi-stage processes with the primary basaltic magma formed by melting of the lower crustal source at the mantle/crust boundary. Following formation of a melt reservoir in the middle crust, accompanied by secondary melting of the surrounding rocks, and/or repeated process of assimilation and fractionation produced a suite of chemically variable lithology from basalt to rhyolites and/or granitic rocks.

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Nature of the mass transfer in subduction zones between the slab and mantle wedge: constraints from the experimental study of multiphase solid inclusions

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Ultrahigh-pressure metamorphic terranes provide unique material for studying the mass transfer between the deeply subducted crust and the mantle. Study of multiphase solid inclusions (MSI) in garnet indicates that peridotites from the Saxothuringian basement of the northern Bohemian Massif may be an example of a metasomatized subduction zone mantle wedge. The closely associated diamond-bearing metasediments (Kotková et al. 2011) showing similar peak P–T conditions of c. 5 GPa and ≥ 1100°C (Haifler and Kotková 2016, Medaris et al. 2015) might represent a source of metasomatizing fluids.

The MSI mostly occur within the ≈ 200–500 µm wide annulus at the rim of millimetre-sized pyrope-rich garnet porphyroclasts. They are equant to elongated, show negative crystal shapes, and 5–40 µm in diameter. Major phases include amphibole, barian mica and carbonates (dolomite ± magnesite), whereas spinel, clinopyroxene, orthopyroxene, garnet II, and apatite, monazite, thorianite/uraninite, chromite and sulphides including pentlandite, are common minor and accessory phases, respectively.

In order to homogenize the inclusions and get additional constraints on peak P–T conditions, experiments were run for 24 hours at the peak conditions of 1075°C and 4.5 GPa, using 200 micron thick double-polished MSI-bearing Grt fragments with no fluid added. The experiments have produced no glass but crystals and voids, the later likely former fluids. Experimentally treated MSI are similar to the natural starting MSI regarding size, shape and presence of carbonates, barian mica, thorianite and pentlandite. Contrasting features with respect to the natural MSI, however, include the absence of hornblende, presence of newly crystallized garnet at the interface enriched in Ca and depleted in Fe compared to the host garnet, and the ternary Ca–Mg–Ba character of the carbonates (instead of magnesite, dolomite and subordinate Ba–Mg carbonate in the natural MSI). The experimental products seem to represent a higher P–T analogue of the natural mineral assemblage, as the coexistence of pargasite, dolomite and magnesite along with spinel in the natural MSI corresponds to pressures below c. 1.8–2 GPa. In addition, the high proportion of voids in the experimental MSI, often located at the inclusion-garnet interface, suggests that a fluid phase present during the experiment (likely rich in H_2O, Cl, F, Na) escaped during subsequent polishing. Based on the mineralogy and experimental behavior, we suggest that the MSI represent a complex hydrous carbonate-silicate supercritical fluid, that may correspond to either (i) a melt trapped at or close to peak conditions, that cannot be quenched to a glass due to its low-viscosity; or (ii) a supercritical fluid that cannot be rehomogenized because, after entrapment, it interacted with the matrix and does not preserve its primary composition; or (iii) a supercritical fluid that was trapped along the retrograde path at P–T conditions different from those of the metamorphic peak.

The MSI composition reflects compositional control of both the host peridotite and the crustal-derived fluids (Čopjaková and Kotková in press). Preliminary bulk major element data for the natural MSI fall in the field of group II kimberlites. Previous experimental work shows that such melts are produced by melting of mantle metasomatized by carbonate melts derived from deeply subducted carbonated pelites.

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Preliminary Sr–Nd–Pb–Hf isotope characteristics of the Slavkov Terrane and the Central Basic Belt, Brunovistulicum, Czech Republic

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Brunovistulicum is an important geological unit situated at the eastern margin of the Bohemian Massif (Dudek 1980). Up to the present day, the age, origin and pre-Variscan evolution of the Brunovistulian microcontinent remain poorly known (e.g., Soejeno et al. 2017 and references therein). Its largest exposure represents the Brno Batholith that is divided into three parts – the Thaya Terrane, the Slavkov Terrane and the Central Basic Belt. While the rocks from the Thaya Terrane were already studied in detail both geochemically (including Sr–Nd isotopes) and geochronologically, the rocks from the Central Basic Belt and especially that of the Slavkov Terrane were studied incomparable less. A new geochronological and geochemical research focused mainly on radiogenic isotopes of Sr, Nd, Pb and Hf might shed light on the highly discussed origin of the Brunovistulian microcontinent.

Both U–Pb dated samples from the surface exposures within the Central Basic Belt (metatuff of the "Metadiabase Subzone" and younger undeformed rhyolite dykes) and the Slavkov Terrane (tonalite/quartz diorite, diorite enclave), including samples from the drill cores of basement crystalline rocks (tonalite/quartz diorite, leucogranite), which are overlain by flysch sediments of the Outer Western Carpathians, have been subjected to our isotope study. The metatuff shows the most primitive initial Sr and Nd composition ($^{87}Sr/^{86}Sr_{(740)}$ = 0.702, $\varepsilon Nd_{(740)}$ = +5.7), followed by tonalites from boreholes ($^{87}Sr/^{86}Sr$ = 0.703–0.704$_{(600)}$, $\varepsilon Nd_{(600)}$ = ~ +3 to +4) and the leucogranite whose $^{87}Sr/^{86}Sr$ corresponds to that of tonalites of the Slavkov Terrane (0.703–0.705), however, εNd of the leucogranite is slightly lower ($\varepsilon Nd_{(600)}$ = –2.7) than that of the latter (~ 0 to +4). The rhyolite samples yielded the highest initial $^{87}Sr/^{86}Sr_{(600)}$ ratios of 0.705–0.707 along with negative $\varepsilon Nd_{(600)}$ (~ –2). The Pb isotope composition of all tonalitic samples plots generally between the orogenic and the upper crust growth curves of Zartman and Doe (1981) and shows a linear trend from less radiogenic $^{206}Pb/^{204}Pb_{(600)}$ of ~ 16 to more radiogenic values. On the contrary, rhyolite samples do not fit the same trend as they have variable $^{207}Pb/^{204}Pb_{(600)}$ ratios between 15.5 and 15.7 at the given $^{206}Pb/^{204}Pb_{(600)}$ ratio. Tonalites from the Slavkov Terrane as well as those from the boreholes yielded relatively uniform $\varepsilon Hf_{(600)}$ (~ 0 to +1.5) with an exception of leucogranite with lower $\varepsilon Hf_{(600)}$ of –12.5.

Majority of samples from the Slavkov Terrane including the samples from boreholes represent a cogenetic suite with uniform isotope composition. Their geochemistry and isotope signature corresponds to primitive volcanic arc with orogenic Pb signature. Rhyolitic and leucogranitic samples are more differentiated, which is supported by a presence of negative Eu anomaly, but it does not exclude that they might be a part of the same I-type suite. Hf isotopes of the Slavkov Terrane display the primitive arc affinity as well, however, the εHf of leucogranite is shifted to values characteristic for Cadomian juvenile crust. Our results suggest that both surface and drill core samples are part of a compact unit of the Slavkov Terrane, which represents an eroded part of the ca. 600 Ma old subduction-related primitive arc. On the other hand, felsic metatuff from the Central Basic Belt with MORB-like isotope signature geochemically corresponds to intraplate geotectonic setting. Regarding its age (~ 740 Ma), it might reflect the processes related with the disintegration of Rodinia.

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Geomagnetic properties of granitoids from the Slavkov terrane (Brunovistulicum) influenced by metasomatic transformation of paramagnetic to ferromagnetic phases

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The Eastern complex of the Brno batholith is dominantly built up by two granitoid varieties manifesting by different petrophysical properties: (1) extremely magnetic biotite-amphibole tonalites ($\kappa \sim 1 \times 10^{-2}$ SI) showing decreased concentrations of radioactive elements (2) biotite granites with slightly higher radioactivity displaying lower susceptibility ca. 1×10^{-4} SI.

The bulk magnetic susceptibility of granitoids is controlled by the presence of pure magnetite (TiO_2 < 0.145 wt %) which originated along with diamond-shaped titanite as a result of the reaction between early magmatic titanomagnetite, annite and anorthite during late-magmatic stages under relatively oxidizing conditions (Broska et al. 2007). The late oxidation of granitoids has led to releasing of Fe^{2+} from mafic silicates and subsequent formation of pure magnetite with increased contents within tonalites due to different whole-rock chemistry (SiO_2 58–65 wt %, FeO 3.98–7.19 wt %, MgO 1.46–3.52 wt %, CaO 3.7–6.05 wt %, TiO_2 0.63–0.89 wt %) and degree of fractionation (Rb/Sr 0.036–0.048, K/Ba 19.434–22.43) reflecting distinct chemical composition of Fe-rich mafic silicates (chamosite ~ 24 wt % FeO) compared to more felsic granites (SiO_2 ~ 67.3 wt %, FeO 2.86–3.04 wt %, MgO 1.08–1.28 wt %, CaO 1.5–1.86 wt %, TiO_2 0.38–0.5 wt %) exhibiting higher degree of fractionation (Rb/Sr 0.085–0.233, K/Ba 30.23–51.91) which typically contain Mg-clinochlore depleted in Fe^{2+} (~ 20 wt % FeO). The substantial source of Fe^{2+} for production of pure magnetite in an evolved and crystallized magmatic system in oxidizing regime appears to be biotite which consumes O_2 as was experimentally proven: Annite + $1/2O_2$ = Magnetite + K-feldspar + H_2O (Wones and Eugster 1965).

The metasomatic mineralogical transformation, well described on examined granitoid varieties of the Eastern complex, apparently had a tremendous impact on the geomagnetic behaviour of entire eastern part of the Brunovistulicum (Slavkov terrane) forming widespread regional magnetic anomalies (Fig. 1) in the basement of younger sedimentary formations of Western Carpathians (Šalanský 1995).

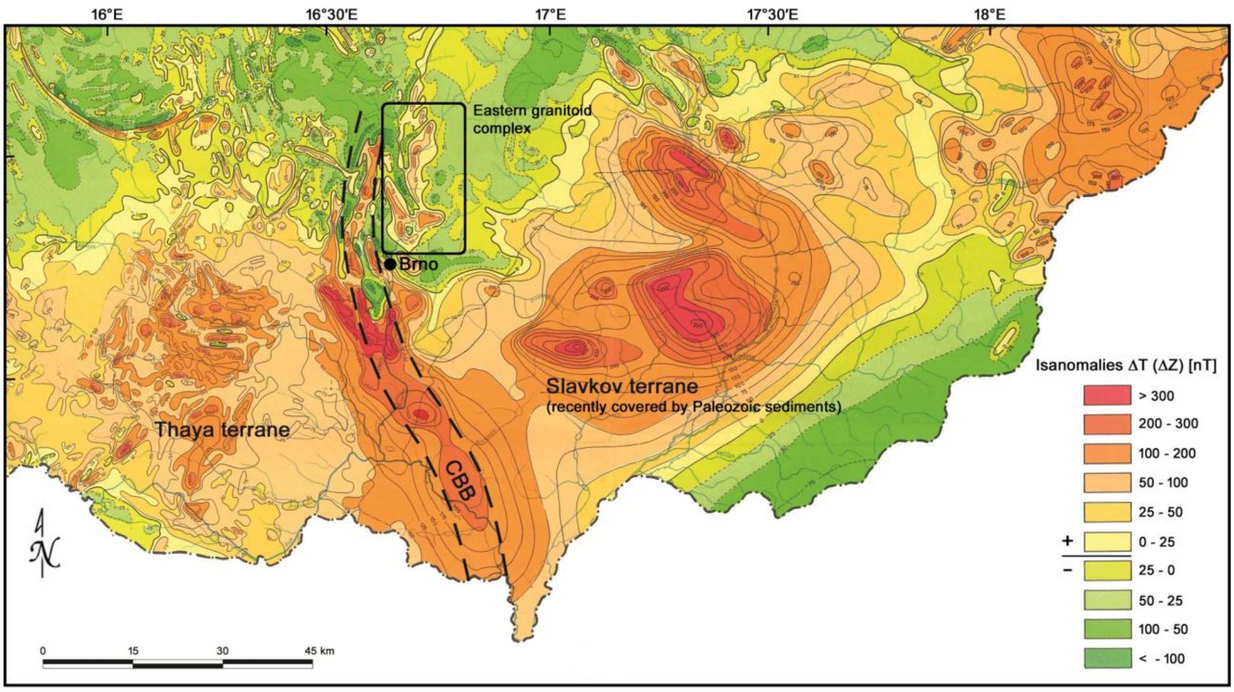

Fig. 1. Widespread magnetic anomalies formed by individual terranes of Brunovistulicum: the Central basic belt (CBB) dividing the Western (part of the Thaya terrane) and Eastern (part of the Slavkov terrane) granitoid complex. Aerogeomagnetic map of the Czech Republic modified from Šalanský (1995).

Where does the Saxothuringian unit get its heat? Constraints and ideas.

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Subduction of the Saxothuringian ocean and the leading edge of the Saxothuringian continental crust is regarded as the driving force for the Devonian–Carboniferous tectonic evolution of the Bohemian Massif (e.g. Konopásek et al., 2019; Schulmann et al., 2009, 2014). The boundary between the Saxothuringian and Teplá-Barrandian domains of the Bohemian Massif, so-called western margin, provides a unique study area to constrain its dynamics through analysis of metamorphic and structural evolution of rocks involved. Recent advances in polyphase structural analyses and thermodynamic modelling together with existing data allow us to unravel the early subduction-related evolution from later orogenic deformations. The most pronounced feature of the studied area is a continuous change of thermal structure evolving from a relatively cold geothermal gradient during subduction, progressive heat accumulation during accretion of subducted material followed by rapid heating contemporaneous with the "internal collapse" of the thickened orogenic root. The idea of foreland-directed lower-crustal flow as a possible process to transport HP–HT rocks providing heat from internal orogenic zones was already proposed by Henk (2000). In this contribution, we elaborate such mechanism in more detail providing the field-based structural and petrological constraints, and summary of our recent views on the geodynamic evolution of the western margin of the Bohemian Massif.

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Two nappes in the Austrian part of the Moravian Superunit

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The Moravian Superunit represents the external part of the Variscan Orogen in Central Europe. Since Suess (1912) identified this superunit in the Thaya and Svratka tectonic windows along the eastern margin of the Moldanubian Superunit, its internal tectonic structure has been debated. Whereas Suess did not consider any tectonic subdivision for the Moravian Superunit, a tectonic concept with two nappes and a parautochthonous unit eventually arose for the Thaya Window (Tollmann 1983, Stípská et al. 1999, Neubauer – Handler 2000). There, the Moravian Superunit would be subdivided into an upper nappe composed mainly of Bittesch orthogneiss, a middle nappe with the ultramylonitic Weitersfeld orthogneiss and a parautochthonous unit represented by the "Thaya Batholith", lithologically related to the Brno Massif. Other models with two (Roetzel – Fuchs 1999) or four nappes (Fritz et al. 1996) were also proposed.

In this contribution, we present a new tectonic nomenclature based on mapping in the Austrian part of the Thaya Window (Austrian geological map sheet 21 Horn). In addition to local ductile and brittle-ductile shear zones, only one major regional thrust with a top-to-NNE kinematic runs through the Thaya Window. This indicates that a nomenclature with only two nappes is needed in the Austrian part of the Thaya Window: the redefined Pleißing and the newly defined Pulkau nappes, respectively. The Moldanubian Thrust forms the hanging wall of the Pleißing Nappe. The ultramylonitic Weitersfeld orthogneiss and the proto- to ultramylonitic Sachsendorf orthogneiss mark their bases in the central part of the Thaya Window and at its southern end respectively. Because there is no continuous shear zone at the base of the Bittesch orthogneiss, this lithological unit is an integral part of the Pleißing Nappe, which contains additionally granodioritic orthogneiss, mica schist, paragneiss, quartzite, calcitic marble, calc-silicate rock and the Weitersfeld orthogneiss, as sheared part of the Cadomian Thaya Batholith. The lower Pulkau Nappe is cut by the Diendorf–Boskovice Fault System in the east and overlain by the Pleißing Nappe in the west. It is composed of variably deformed granitoids and granodioritic orthogneiss from the Cadomian Thaya Batholith, mica schist, paragneiss, quartzite and minor calc-silicate rock. It is similar to the core of the Svratka Window.

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Geophysical constraints for suture zones in the Precambrian blocks of the Mongolian collage, Central Asian Orogenic Belt

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The Mongolian collage represents the eastern part of the Central Asian Orogenic Belt (CAOB), which is an accretionary orogen composed of Precambrian continental blocks, oceanic crustal fragments, accretionary complexes, island arcs, back-arcs and ophiolites. It formed from Neoproterozoic to Jurassic (e.g. Şengör et al. 1993). This orogen is of great interest due to its enigmatic and still not completely understood geodynamic evolution. Two principal models are proposed to explain the tectonic assemblage and the material redistribution of the Mongolian collage. (1) Several studies asserted that the Precambrian blocks located north of the Mongol–Okhotsk suture zone were already accreted to the southern margin of the Siberian craton in the Cambrian (e.g. Gladkochub 2010) while the geological units south of the suture were part of the Gondwana margin and collided along a linear subduction zone only in the Late Paleozoic – Mesozoic times (e.g. Zonenshain 1973). In contrast, (2) the crustal structures of the Mongolian collage indicate the possible presence of an orocline, which formed during the closure of the Mongol–Okhotsk Ocean in the Late Jurassic – Early Cretaceous (e.g. Şengör et al. 1993, Lehmann et al. 2010). This orocline is supported by the apparent continuity of the Precambrian continental ribbon blocks in the shape of a horse-shoe. To assess whether the horse-shoe shape is only an apparent feature resulting from multiple accretions of independent blocks or the result of oroclinal bending of a continuous ribbon, the identification of suture zones is one of the keystones. On the one hand, if several suture zones dividing individual Precambrian units are detected, it will serve as an argument for the accretion of contrasting terranes and closure of oceanic basins. On the other hand, if no specific suture is observed in this part of the CAOB, it will establish the continuity of the Precambrian blocks and the existence of a large and folded continental ribbon. In this study, we use potential field data from the Earth gravitational model EGM2008 (Pavlis et al. 2012) and from the Earth magnetic anomalies model EMAG2 (Maus et al. 2009), in order to detect the possible cryptic suture zones between the Precambrian blocks. As suture zones are intracontinental deep-seated, steeply dipping high-strain zones associated with remnants of ophiolites or HP mafic rocks (Dewey 1977), they display strong gravity and magnetic gradients. The location and trend of major gradients are determined using specific data filtering technics such as spectral and multi-scale edge analyses, pseudo-gravity and tilt derivative transformations, which provide information on the significant crustal structures and their continuity in depth. The interpreted gravity and magnetic lineaments, correlated with previous lithological and structural studies will enable the examination of both the surface and deep crustal architecture of the orogeny, and the assessment of the presence of suture zones.

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The Late Cenozoic activity of the northern branch of the Vienna Basin Transform fault system (studies in the Orava Basin – a structural approach)

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The NE–SW directed, ca. 300 km long Vienna Basin Transform fault system (VBTF) extends from the Eastern Alps into the Polish part of the Western Carpathians. The studied Orava Basin (OB) developed within the northern branch of the VBTF is a tectonic structure filled with Neogene and Quaternary deposits superimposed on the collision zone between the ALCAPA and European plates. OB is a complex strike-slip-related basin formed in transtensional conditions, with some features of a transrotational basin (Ludwiniak et al. 2019; Fig.1). Regional NE–SW trending Krowiarki (KFZ) and Hruštinka – Biela Orava (HBOFZ) sinistral fault zones belonging to the VBTF were recognized as key tectonic features influenced the OB development (Fig.1). The interaction of these sinistral fault zones with the older, ca. W–E trending tectonic structures of the collision zone caused the initiation and further development of the OB as a strike-slip-related basin. W–E trending normal faults constituting the southern and northern OB margins are structures of lower range with regard to the sinistral KFZ and HBOFZ regional fault zones and play the role of compensation structures. DEM analysis combined with palaeomagnetic data (Tokarski et al. 2016) indicate that sinistral displacements along the KFZ and HBOFZ bounding the OB were compensated (at least partly) by counter-clockwise rotations of basement blocks according to the bookshelf mechanism (Mandl 1987; Fig.1). Faults separating individual blocks were primarily formed as R' and T secondary faults, feathering the main sinistral fault zones. Such a manner of compensation of strike-slip movement probably influenced the complex character of the basin.

The KFZ separates areas characterized by different deformation patterns within the Central Carpathian Palaeogene Basin (CCPB). The most pronounced feature is a different pattern of the joint network on both sides of the KFZ. The area on the eastern side of the KFZ (Podhale area) is characterized by a dominating occurrence of diagonal joint systems, whereas the domination of the orthogonal joint systems has been observed on the western side of this zone (south-eastern Orava area). It points to differences of palaeostress fields acting on both sides of the KFZ. Podhale was the area of stronger longitudinal compression in comparison to the south-eastern Orava area. Taking into account that the CCPB joint network was generally initiated at a very early stage of structural development in horizontal, non-deformed rocks (Ludwiniak 2010), it may be assumed that the KFZ within the CCPB was active earlier than hitherto accepted, already from the earliest Miocene (i.e. at least from the time of cessation of the Central Carpathian flysch sedimentation). Comparison of structural data with the recent tectonic stress field (Jarosiński 1998), earthquake focal mechanisms (Wiejacz – Dębski 2009), GPS measurements (Grenerczy et al. 2000, Łój et al. 2009) and thermochronological data (Śmigielski et al. 2016) allows us to conclude that the KFZ shows a stable general pattern of tectonic activity for more than the last 20 myr and is presently still active.

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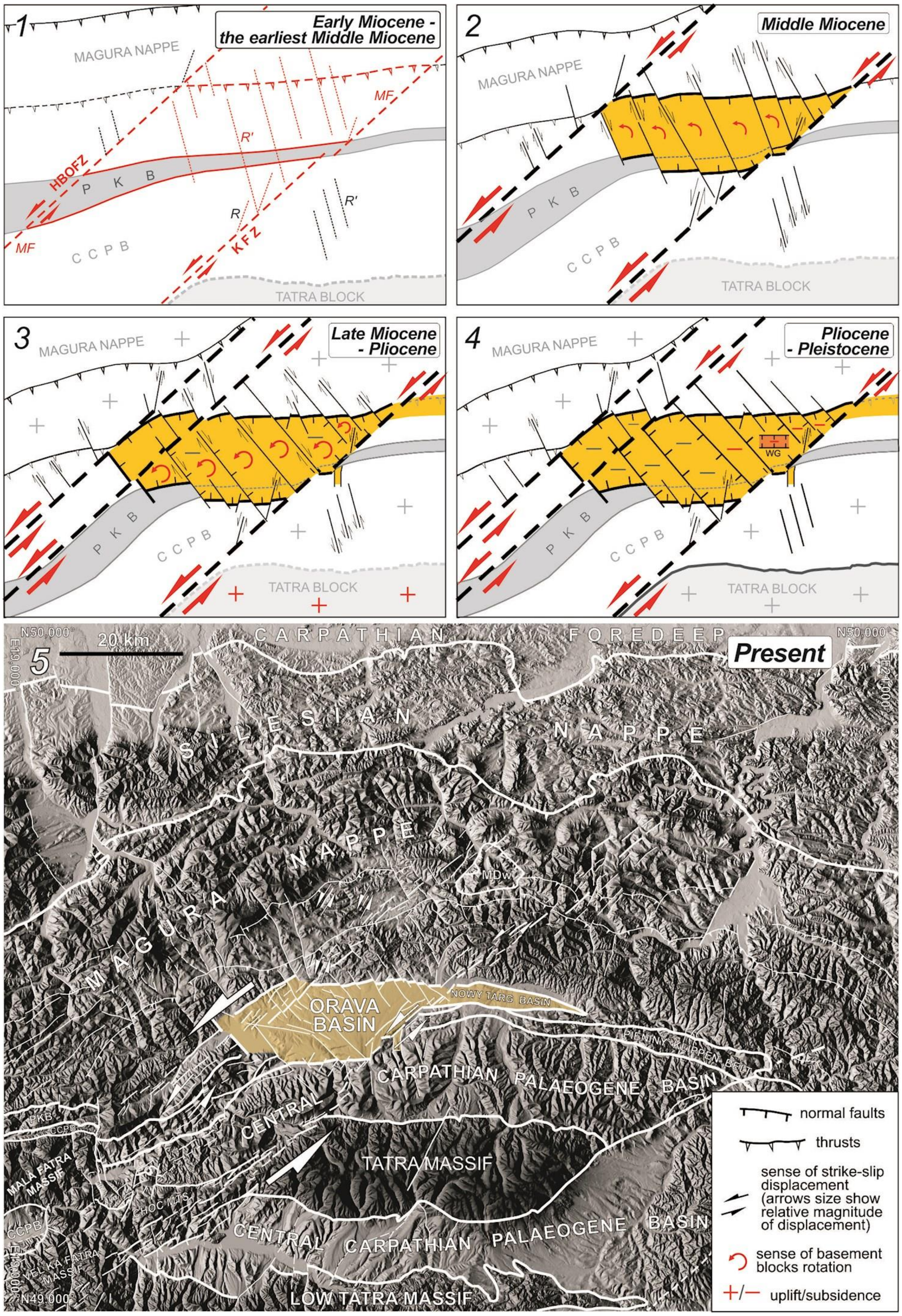

Fig.1. Orava Basin development (1–4). (5) Orava Basin in relation to adjacent units of the Western Carpathians. Traces of selected map-scale faults and main thrusts are depicted only. PKB – Pieniny Klippen Belt.

Magnetic fabric vs. sedimentary facies in rocks of the Central Carpathian Palaeogene Basin (Central Western Carpathians, Slovakia)

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The anisotropy of magnetic susceptibility (AMS) is a well recognized petrofabric tool, which has been successfully used on a wide range of geological problems (Tarling – Hrouda 1993). A sedimentary magnetic fabric is characterised by the cluster of minimum susceptibility axes (K3) near the bedding pole, due to deposition/compaction. In the absence of flow during deposition, the intermediate (K2) and maximum susceptibility axes (K1) are intermixed in the bedding plane, otherwise the K1 axes (magnetic lineations) are oriented either parallel or perpendicular to flow direction, depending on the flow velocity and inclination of deposition slopes. During incipient deformation, the K1 axes progressively rotate to the direction perpendicular to bedding parallel shortening, i.e. to the bedding strike, fold axis direction or to cleavage/bedding intersection, while the K3 axes remain close to the bedding pole. With increasing deformation the K3 axes start to create a girdle parallel to the compression direction and perpendicular to K1.

From the Central Carpathian Palaeogene Basin (CCPB) either sedimentary fabrics or tectonic fabrics superposed on primary sedimentary fabrics were reported from the Liptov Basin and Orava region (Hrouda – Potfaj 1993, Hrouda et al. 2018). In contrast, primary sedimentary magnetic fabrics formed by deposition from turbidity currents have been revealed in the Podhale and Levoča Basins, inferring that the AMS fabrics might be used as a proxy for paleoflow direction estimation (Márton et al. 1999, 2009).

The aim of this study was to investigate the AMS of different sedimentary facies, including mudstones deposited most probably in a quiet environment and fine to medium grained sandstones of the classical Bouma divisions, deposited in various flow hydrodynamic regimes. We sampled 208 independently oriented cores from 10 localities in the Spišská Magura Mts., Liptov and Orava regions of Slovakia. For comparison we used the AMS data from 14 localities in the Levoča and Podhale Basins (Márton et al. 1999, 2009). We observed magnetic susceptibilities in the range of 120–310 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. In massive or laminated mudstones, the K3 axes were always clustered at the respective bedding poles. The K1 axes were well-grouped and parallel to paleoflow directions, measured from the nearest sandstone bed. In massive or parallel laminated sandstones, the K3 axes were perpendicular to bedding and the K1 axes were well-grouped and parallel to paleoflow directions. In cross-laminated sandstones, the K1 axes were oriented either parallel or perpendicular to the flow direction, but the magnetic lineations were poorly constrained. In convoluted sandstones with water escape structures and in the sandstone beds containing syn-sedimentary slumping folds, the K3 axes created a girdle perpendicular to the K1 axes. In this case, a weak tectonic overprint due to bedding parallel shortening may be inferred. Alternatively, this fabric may have been formed during syn-sedimentary deformation on slopes, while the sediment was still wet and poorly lithified. The above results suggest that the AMS fabric can be a viable supporting tool to traditional paleocurrent analyses in the CCPB, especially in the absence of sedimentological indicators.

Acknowledgments
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How many types of primary fabric could be in one dyke?

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Recent theory gives a cause of origin of three perpendicular structure types in magmatic dykes to magmatic and postmagmatic processes. This work discusses the existence of all these types in one dyke in data from tectonic and metamorphic stable area of James Ross Island, Antarctica.

It is very easy to reach the significant and accurate data using the anisotropy of magnetic susceptibility method and measuring the dependence of magnetic susceptibility on temperature method.

The occurrence of reversible low-Curie temperature curves (110 and 160°C) indicates no regional hydrothermal alteration and proves existence of only primary magmatic fabrics in studied basalt dykes. Remarkable type zonality from margin to centre of dyke refers to changing of types in time due to external conditions variability (Fig. 1).

Type A is similar to “normal” magnetic fabric where the magmatic flow plane is parallel to dyke wall. This type of magnetic structure is typical for chilled margin of the dykes and it is a result of rapid cooling during fracture opening and initial magma emplacement.

The zone of vesicles represents the transitional type AB where the structure is more-like chaotic indicating the magmatic flow plane changes.

The type B is where the magnetic lineation is parallel to magmatic flow and magnetic foliation is perpendicular to dyke plane and occurs mostly in central part of dykes. Such a structure reflects the change of magmatic flow plane caused by magma cooled near the surface.

Last type C is perpendicular to types A and B. This type was found in the end of the dyke where the cracking of the host rock was stopped, and cumulating magma changes the magmatic flow plane.

The four magnetic types of primary fabric in basalt dykes assigned to 3 phases of dyke development has been described. The explanation of their origin is in magmatic flow plane changes in time of magma emplacement and forming the dyke.

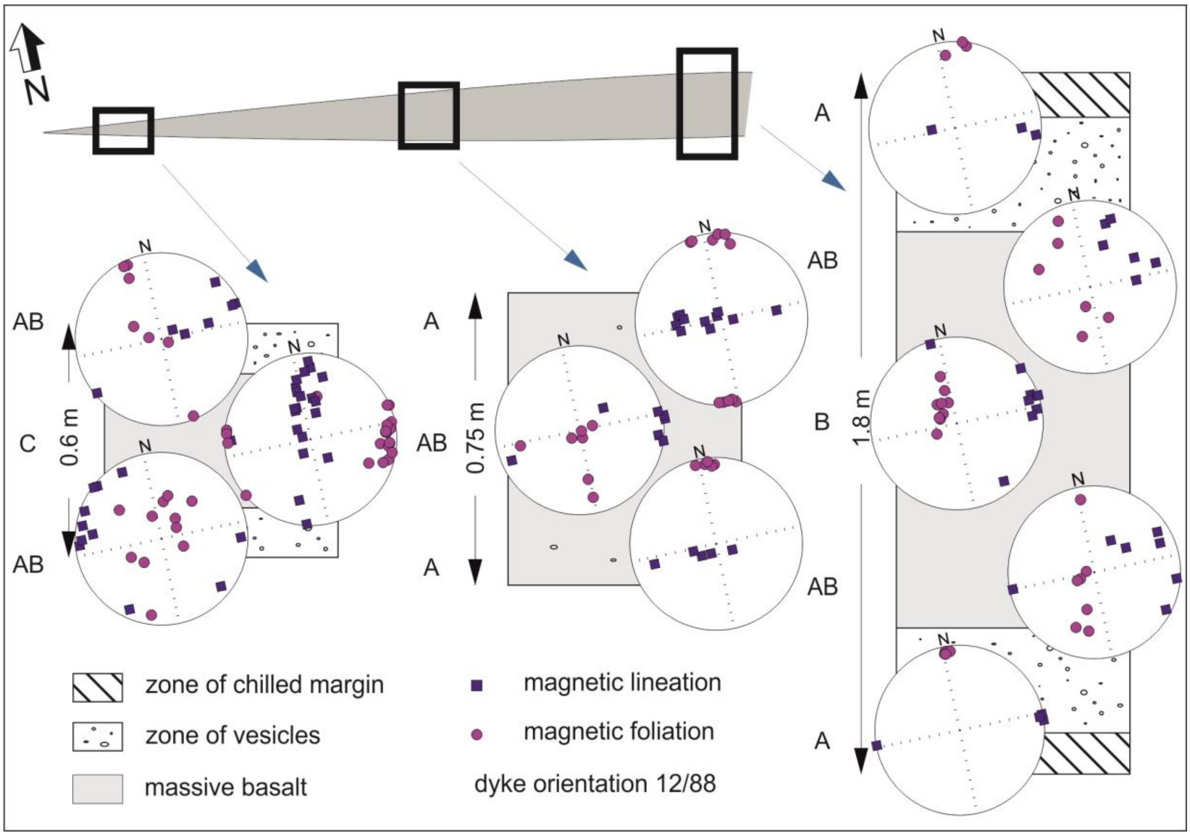

Fig. 1. Three segments of basalt dyke with detailed anisotropy of magnetic susceptibility analysis. Data sorted by magnetic fabric orientation are visualised in equal-area projection.

Last scene in the large scale displacements of the Western Carpathians: paleomagnetic constraints

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This paper will evaluate the robust sets of Paleogene paleomagnetic and magnetic anisotropy (mostly AMS) results from the rootless Silesian, Dukla and Magura nappes and the Paleogene cover of the Central West Carpathians (total of 88 geographically distributed localities), as well as from the Upper Cretaceous red marls of the Pieniny Klippen belt (14 localities representing the Polish and Slovak segments). All these units were most intensively deformed in the Miocene, before the accretionary wedge was thrust over the Miocene fill of the Carpathian foredeep.

The geological/tectonic processes leaving their imprints in the magnetic anisotropy and the paleomagnetic properties of the Paleogene flysch are the followings. Sedimentation/compaction resulted in bedding parallel magnetic foliation. This was preserved during tectonic deformation. Imprints of weak tectonic deformation in the AMS fabrics related to Miocene compression are typical in the Silesian (particularly in the Eastern segment) and Dukla nappes, while results from the Magura nappe seem to be reflecting a complex history of orientation by sedimentary flow, syn and post-sedimentary deformation. The AMS lineations of the Central Carpathian flysch from the Podhale and Levoca basins are basically related to sedimentary transport. Concerning the red marls of the Pieniny Klippen belt, the AMS fabrics must be due to more intensive and more complex tectonic processes than those of the Paleogene sediments N and S of the belt.

All the above discussed units exhibit large CCW rotations. Its lower age limit is constrained by the fact that remanences of pre-folding age (typical for the western and central segments of the Silesian nappe and for the Central Carpathian Flysch) and of post-folding age (typical for the Magura nappe) as well as the mixed population of the pre- and postfolding remanences in the Eastern segment of the Silesian nappe exhibit this large rotation. This situation implies that the folding of the respective units predates the CCW rotation.

The termination of the large scale CCW rotation to date is a matter of speculation. Paleomagnetic studies that may be relevant to this problem were carried out in the Rzeszów, Nowy Sacz, Orava and Turiec basins on Miocene sediments and on the Pieniny andesites. Apart from the first, all provided positive paleomagnetic results, which will be discussed in the context of the reliability of age assignments of the studied rocks, the ages of the acquisition of the paleomagnetic signals and their relevance to the final emplacement of the Outer Western and the Central Carpathians.

Is the Hamburg–Kraków–Dobrogea Fault a fossil plate boundary of Avalonia?

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The Kraków–Lubliniec Fault is a long-lived and polydeformed contact zone between the Brunovistulian Terrane (BVT) and the Małopolska Block adjacent from the north. The fault is a segment of a longer feature, the Hamburg–Kraków–Dobrogea Fault, the dissects the European continent in a NW–SE direction from the North Sea to the Black Sea. The Hamburg–Kraków–Dobrogea Fault separates Baltica and, potentially, Baltica-derived terranes in the NE from peri-Gondwanan terranes in the SW. The latter terranes, showing record of Cadomian magmatism and metamorphism, were accreted and subsequently displaced and reorganized during the Caledonian, Variscan and Alpine orogenic cycles. One of them was the BVT the origin of which has been subject to contrasting interpretations. A peri-Gondwana origin of the BVT and its link to the South American section of the Gondwana margin was postulated by Moczydłowska (1997), Finger et al. (2000), Friedl et al. (2001), Bełka et al. (2002) and Mazur et al. (2010). Some other authors advocated a peri-Baltic origin of the BVT, linking it to the present-day SE edge of this palaeocontinent (Winchester et al. 2002, Nawrocki et al. 2004).

The existence of an important crustal boundary between the BTV and the Małopolska Block is confirmed by geophysical data showing a major vertical discontinuity down to the lower crust that separates two blocks with a contrasting velocity structure (Malinowski et al. 2005). Kinematic analysis of the Kraków–Lubliniec Fault indicates intervening phases of dextral and sinistral displacements (Żaba 1999). Also, the sedimentary cover of the BTV and the Małopolska Block, on both sides of the fault, become comparable only from the Lower Devonian onwards.

Our preliminary detrital zircon data form the lowermost Cambrian (Sub-Holmia) sandstone of Upper Silesia (Ogrodzieniec-2 borehole) and an Ediacaran sandstone clast (Truskawiec, Ukraine) show a predominant population of Ediacaran zircons linked to a Cadomian orogenic event. Moreover, detrital zircon spectra older than 1 Ga reveal a conspicuous resemblance to those typical of the East European Craton. Consequently, it can be tentatively assumed that a distal margin of the craton was involved in the Ediacaran orogenic event or the BVT represents a segment of the Scythian orogen that was displaced along the Hamburg – Kraków – Dobrogea Fault.

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Lithology and paleotectonic significance of the Middle Triassic syn-rift sequence of the Turňa Unit (Western Carpathians)

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The Turnaicum is a nappe system sandwiched between the Meliatic complexes and overriding Silica cover nappe. It includes low-grade metamorphosed Upper Paleozoic to Triassic formations. Older part is represented by Pennsylvanian to Lower Triassic clastic deposits, followed by lower to middle Anisian ramp and platform carbonates. Overlying deepening succession consists of pelagic sediments – upper Anisian red and Ladinian grey cherty limestones, Carnian dark shales and sandstones, and Upper Triassic cherty and nodular limestones. The Turňa Unit forms a flat-lying, but intensely folded thrust sheet. The investigated section occurs in the steep southern limb of a northward-overturned syncline (Lačný et al. 2016, 2018).

The rapid mid-Anisian (Pelsonian) change from carbonate shelf sedimentation to deep-marine deposition is considered as the regionally important tectonic event related to rifting and ensuing opening of the Meliata Ocean (e.g. Kozur 1991). In the present ambiguous views, the Turňa and analogous units should have been located on either the northern (European) or southern (Adriatic) margin of the Meliata Ocean.

To decipher this controversy, we have investigated a continuous, about 13 metres long artificial trench section located near village Hrušovo (ca. 15 km north of Rimavská Sobota; N 48°31′12.5″, E 20°02′55.9″) that exposes transitional strata between the middle Anisian platform limestones and the Ladinian–Norian basinal deposits.

The base of the studied section is formed by a carbonate breccia consisting of angular clasts of white crystalline limestones and dolostones obviously derived from the underlying Anisian carbonates. Some limestone clasts contain allochems, spicules and uniserial, Nodosaria-type foraminifers. Breccia matrix is composed of dolomite mud and Fe–Mn oxide–hydroxides. Tiny dolostone clasts (below 50 μm) embedded in dolomite mud were dedolomitized during diagenesis and incipient metamorphosis – dolomite is still preserved in their cores and is surrounded by Mn–Ca–Mg carbonate rimmed by about 5 μm thin Mn-calcite margin.

Substantial part of the section (about 6.5 m) is formed by very fine-grained (below 25 μm) carbonate mudstones. Besides carbonates, they contain Fe and Mn oxides causing red-brown to black colouration, silty quartz and accessory chlorite, biotite, albite, apatite, sericitic muscovite and rarely also monazites and rounded zircons. In places, tiny laminae (2–3 mm) of fine-grained siliciclastics with graded bedding (distal turbidites) occur. They are predominantly composed of quartz and albite, while sericite, chlorite, Mn-calcite, Fe and Mn oxides, apatite, zircon, rutile and rarely also monazite are the subordinate components.

The sequence of carbonate mudstones is followed by 70 cm thick horizon of volcanic ash composed purely of minerals of the zeolite family. Lack of the carbonate mud and Fe–Mn oxides in this horizon indicates its origin from an air-transported volcanic ash deposited in a deep-marine environment.

The volcanic layer is overlain by about 5 m thick layer of carbonate mudstone with frequent, 50 μm to 1 mm thick hydrothermal veinlets formed by dolomite, Mn-dolomite, kaolinite and Mn oxides. In an outcrop close to the studied section, grey siliciclastic sediments with a similar composition are exposed. They are increased in the carbonaceous matter and contain fragments of silicified calcareous ooze with benthic foraminifers and filaments.

In general, lithology of investigated rocks corresponds to sedimentary environments at a distal continental margin at the transition to an oceanic domain. Their age is not exactly known, but relationship with the Late Anisian – Ladinian Tethyan rifting accompanied by clastic sedimentation and intermediate to acid volcanism (e.g. in the Bükk Mts – Veledits 2006; Kövér et al. 2018) is inferred. In our opinion, the investigated Middle Triassic deposits of the Turňa nappe show affinity rather to the southern (Bükkian) than to the northern (Gemeric) margin of the Meliata Ocean. This interpretation is corroborated by the upper structural position of Turnaic units in the composite Meliatic–Turnaic accretionary complex overriding the Gemericum (Plašienka et al. 2019).

We have also dated very fine-grained (below 30 μm) monazite grains occurring in siliciclastic sediments and also in silicified calcareous ooze. Preliminary results of the chemical (EMPA) U–Th–Pb monazite dating indicate presence of clastic grains derived from Upper Paleozoic complexes and probably diagenetic to very low-grade metamorphic, burial-related monazite crystals of the Late Triassic age.

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Determining the orientation of a sub-horizontal contact lying within Kraków-Silesian Homocline (Poland) – on selected problems with application of Delaunay triangulation and cluster analysis

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According to the common belief, sediments of the Kraków-Silesian Homocline are dipping gently in the north-eastern direction. This orientation has been present since the Late Cimmerian Phase (e.g. Górecka 2013), however, its definite shape has been fixed in the Alpine orogeny (Laramide phase) in the Late Cretaceous (Górecka 2013, Rutkowski 1989). The accurate orientation of the sediments in the form of dip angle and dip direction has not been determined yet and only rough estimations are provided in the literature. In our approach, we incorporate Delaunay triangulation and cluster analysis to determine the orientation of a sub-horizontal interface separating younger ore-bearing clays deposits and older sands and sandstones. We discuss advantages and disadvantages of some rival approaches, such as:

- Basic interpolation and discrete smooth interpolation,
- Least-square method,
- Geostatistical approaches (e.g. co-kriging),
- Analysing spherical distributions (e.g. von Mises-Fisher, Kent),
- Mixture models involving clustering and spherical distributions.

We present also certain difficulties, interpretational problems and questions involving sedimentary and computational considerations. These of sedimentary nature arise due to a hiatus between lithological units evidenced by the lack of *Strenoceras Subfurcatum* Ammonite zone. The computational difficulties address the selection of adequate distance measure when clustering. We believe that the following example can be illustrative. In the problem of joint clustering, sub-vertical joints dipping in opposite directions are often assumed to be similar (Hammah – Curran 1999). In consequence, researchers following this approach suggest using angular distances instead of the Euclidean. This is because the latter produce large distances for sub-vertical joints dipping in opposite directions and do not allow them to be clustered together. This assumption, however, not necessarily should be applied in our case, given that *a priori* knowledge suggests only one preferred direction of dip.

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Preserved in a Variscan suture, originally late Cambrian and arc-related – considering tectonic affinity of the Leszczyniec Unit, Sudetes, Bohemian Massif

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The tectonic affinity of the Leszczyniec Unit is interpreted according to two, alternative hypothesis. The first one postulate that the Leszczyniec Unit is a fragment of the lower Paleozoic, oceanic crust, preserved in a suture between Saxothuringia and Tepla-Barrrandian terranes. The concept of oceanic origin is based on whole rock geochemistry and the presence of the Paczyn Gneiss, a trondhjemite-type rock variety (Szałamacha – Szałamacha 1991, Narębski et al. 1986). On the other hand, the subsequent geochemical results (Winchester et al. 1995; Kryza et al, 1995) and radiometric ages of 500 Ma (Oliver et al. 1993; this study) may suggest a Tepla-Barrrandian affinity of the Leszczyniec Unit. The latest Cambrian age is typical of the rift-related, volcano-sedimentary and igneous suites that are widely distributed in the Variscan belt. In such a case, protolith of the Leszczyniec Unit may represent mafic lower crust – a product of syn-rift underplating. The Stare Město Belt (Štípska et al. 2001), Křivoklát-Rokycany Complex (Pin et al. 2007) as well as Marianske Lazně Complex (Štědra et al. 2002) can provide regional analogues.

The Karkonosze-Izera Massif is interpreted as a stack of tectonic units assembled by Variscan thrusting during the collision between the Saxothuringian and Tepla-Barrandian terranes (e.g. Mazur – Aleksandrowski 2001, Jeřabek et al. 2016). The collision was a consequence of the closure of a possible branch of the Rheic Ocean, known as the Saxothuringian Ocean. The Karkonosze-Izera Massif nappe structure recorded continuous subduction and underplating of imbricated thrust sheets, derived from the Saxothuringian lower plate, to the base of the upper plate that has been considered a northern prolongation of the Tepla-Barrandian domain (Mazur – Aleksandrowski 2001, Jeřabek et al. 2016). The Leszczyniec Unit comprises a differentiated suite of mafic and felsic rocks of volcanic and plutonic origin. Fine-grained schistose and medium-grained massive Leszczyniec metabasites include several large sill-like bodies of the Paczyn Gneiss. The latter comprises a wide range of rock types from felsic to hornblende-bearing gneisses (Kryza et al. 1995) derived from metagranites and metadiorites, respectively. The overall geochemical characteristics point to N-type MORB affinities of the Leszczyniec meta-igneous complex (Kryza et al. 1995, Winchester et al. 1995). It is only the metadiorites that are reminiscent of island-arc lavas (Narębski et al. 1986) or, alternatively, have formed through crustal contamination of rift-related magmas (Kryza et al. 1995, Winchester et al. 1995). It is hypothesized (Kryza et al. 1995) that the protolith of the Leszczyniec Unit was emplaced in an extensional rift setting, though the observed large proportion of felsic rocks seems to preclude a mature oceanic rift. Our geochemical investigation through the ICP-MS bulk chemistry analyses of major and trace elements reveals, as first, a strong metamorphic overprint on the Leszczyniec Unit metaigneous rocks. The fine-grained metabasites have N-MORB geochemical signature, whereas the metafelsic rocks partially display anomalies suggesting possible accumulation or crustal contamination. The hornblende-rich Paczyn Gneiss shows fairly flat, depleted and uneven REE patterns, relatively enriched in LREE. High V and low Ti content, points to their island arc tholeiitic origin. The fluid and sediment melt influence is visible in the Paczyn Gneisses suggesting, in comparison to literature data, a probable input from the Lusatian greywackes (e.g. Linnemann – Romer 2002). In addition, the subduction zone indicators as depletion in Ta–Nb, Sr and Ta as well as La–Y–Nb and Zr/Yb ratios trends, point to the island arc-related setting for the whole Leszczyniec suite. The further, isotopic and petrological investigations are in progress.

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Detrital zircon geochronology and heavy mineral provenance of Late Paleozoic to Late Cretaceous sedimentary basins of the northern Bohemian Massif

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From Permian to Late Cretaceous, the northern Bohemian Massif experienced a complex intra-plate tectono-sedimentary evolution involving development of at least four generations of sedimentary basins in different settings. Expanding on the previous study of Hofmann et al. (2018), we examine this protracted evolution using stratigraphic changes in sediment provenance, analyzed through heavy mineral assemblages and U–Pb detrital zircon geochronology (by laser ablation ICP-MS, Fig. 2) in Permian, Jurassic, and Late Cretaceous successions (Fig. 1).

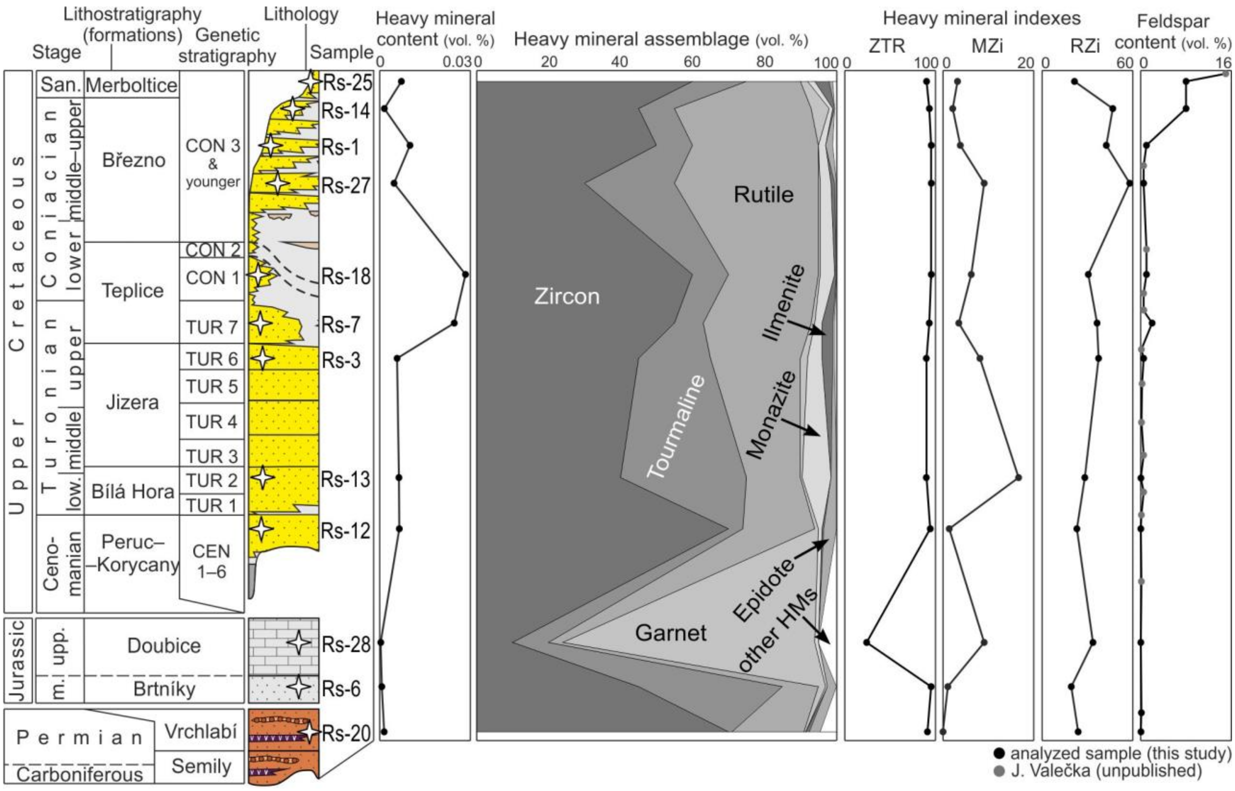

Fig. 1. Stratigraphic variations in the heavy mineral assemblages. ZTR – zircon–tourmaline–rutile index, MZi – monazite–zircon index, RZi – rutile–zircon index. Feldspar content compiled from this study and unpublished data (J. Valečka).

The provenance data point to multiple, temporally evolving sources ranging from local (e.g., the 'West Sudetic Island') through more distant from elsewhere in the Bohemian Massif to exotic, likely derived from Baltica. The latter is interpreted as a trace of now completely eroded Late Jurassic to Early Cretaceous basin that once covered the Lusatian block (cf. Voigt 2009) and received the Baltica-derived detritus, evidenced by presence of Mesoproterozoic zircons delivered by northerly fluvial and deltaic depositional systems. We suggest that fill of this basin was recycled into the Bohemian Cretaceous Basin during progressive unroofing of the West Sudetic Island. A time-slice reconstruction of the paleogeographic and tectono-sedimentary evolution of the northern Bohemian Massif shows that periods of basin development and deposition (Early Permian, Late early Permian to Early Triassic, Middle Jurassic – Early Cretaceous, Late Cretaceous) were interrupted by major depositional gaps (Middle Triassic – Early Jurassic, mid-Cretaceous, post-early Campanian). The Mesozoic depositional episodes resulted from reactivation of major NW–SE strike-slip fault zones due to stress transfer from the North Atlantic Rift during Jurassic to Early Cretaceous, overridden by the far-field effect of convergence of Iberia, Africa, and Europe during Late Cretaceous (Kley – Voigt, 2008).

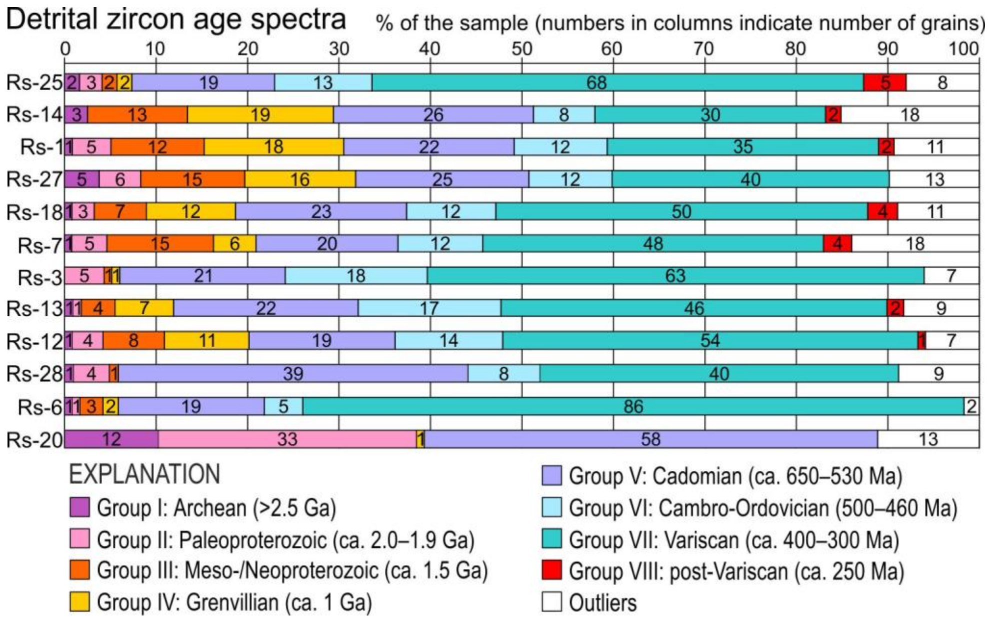

Fig. 2. Frequencies of the detrital zircon age groups in each of the analyzed samples plotted in a stratigraphic succession.

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Exhumation of subducted continental lower plate in the arc region

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The Kutná Hora crystalline complex (KHCC) in the Bohemian Massif is a partially molten H*P*/H*T* complex adjacent to the magmatic arc. It is dominated by migmatite, orthogneiss and felsic granulite with bodies of eclogite and peridotite. The KHCC migmatite consist of K-feldspar, plagioclase, quartz, white mica, biotite, garnet, kyanite, apatite, rutile, zircon and monazite. Melting conditions were estimated at 780°C and > 16 kbar in the stability field of white mica (phengite) and obtained melt volume ranges from 1 to 4 vol %. Peak temperature of 865°C at 18–19 kbar is defined by first kyanite appearance. The occurrence of biotite with second generation of kyanite replacing white mica indicates subsequent decompression in the presence of melt to 12–13 kbar and 770–800°C. White mica proportion along the whole inferred P−T path is high and varies between 15 and 22 vol. %. U–Pb monazite geochronology reveals spread of ages from c. 550 Ma to 330 Ma. REE patterns show first low Yb/Gd ratio for 550−500 Ma, high Yb/Gd ratio for a cluster of ages at ~ 480 Ma, and decreasing Yb/Gd towards ~ 340 Ma. First monazite in equilibrium with garnet is about 350 Ma and thus constrains the H*P* metamorphism to ~ 350 Ma, which is followed by recrystallization of monazite down to 325 Ma. U–Pb zircon geochronology displays continuous age range from ~ 670 Ma to ~ 430 Ma. The broad age range records span of protolith crystallization and/or old metamorphism and due to metamict thin rims on zircons no zircon age of the younger H*P* metamorphism was determined. Presence of HP ky + mu migmatite, their P–T path with H*P* anatexis, protolith zircon ages and monazite metamorphic ages and whole-rock geochemistry including REE patterns are strikingly similar to HP migmatites and granulites in Eger crystalline complex (ECC) in Saxothuringian domain further in the west. Based on these similarities, obtained time scales and metamorphic conditions we propose following geodynamic scenario of subduction–relamination–exhumation mechanism: (i) subduction of the Saxothuringian continental lithosphere at 360 Ma related to early stage of trans-lithospheric diapirism triggered by arc-related magma weakening; (ii) large scale emplacement of relaminant into the upper plate lithosphere at 350–340 Ma; and (iii) return flow of relaminant along subduction interface (the ECC) and emplacement of relaminant in the upper – middle crust in the rear part of the arc system (the KHCC) at 340–330 Ma. Finally, this study highlights the importance of the arc region for the exhumation of the relaminant from asthenospheric depths. The arc served as zone of weakness exploited by hot and weak relaminant during its sequential ascent to upper crustal levels.

Several generations stratabound and vein mineralization as a product of multiple orogenic cycles in the Western Carpathians

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Metallogenic processes strongly relate to individual phases of orogenic processes. Multiple orogenic cycles in the Western Carpathians (Variscan – revealed deformation phases VD0-2, metamorphic overprint M1 and Alpine deformation phases AD1–4, metamorphism M2) produced several generations of mineralization. The regional zonality of mineralization types is a reflection of a geodynamic environment, but also principal metallogenetic prerequisites, encompassing the availability of the primary sources of metals, availability of the reason of the deliberation of these metals from the host lithology (most frequently during the temperature increase) and their transport and accumulation to a new host rock environment. The rifting phases of orogenic cycles produce dominantly the stratabound mineralization. The metallogenic processes related to post-collisional metamorphic core complexes produce predominant vein mineralization, similarly as the island- or continental-arc environments. In our interpretation, the Intra-Pangea thermal processes play a principal role in the metallic elements deliberation from the source rocks into fluids, forming appropriate extensional structures being infilled with these fluids, and thus forming new mineral deposits and occurrences. These processes are attributed to increased heat flow caused by an inferred elongated (linear) heat source (mantle plume; hot line), preferably of equatorial or meridional courses. So, in our interpretation the linear sources of the heat represent not only a driving force for orogenic processes, but produce also "the metallogenetically appropriate geodynamic conditions".

Four principal metallogenetic periods were distinguished in the Western Carpathians (cf. Németh et al. 2016): (1) Early Paleozoic Variscan riftogeneous phase, (2) Variscan collision of the Paleo-Tatric-Veporic block with Paleo-Gemeric zone, origin of post-collision metamorphic core complex in the Paleo-Gemeric and neighbouring Paleo-Veporic zones in Permian with the contribution of the mantle heat (hot line) and dominant location of the metallogenetic processes there, (3) the Late Cretaceous Paleo-Alpine post-collision phase with the additional mantle heat produces Alpine metamorphic core complex in the Veporic terrane and prevailing extension regime, and (4) Miocene Neo-Alpine volcanism-related mineralization phase.

The principal metallogenetic processes (economically the most important ore reserves generation) of the Permian age are located in the Paleo-Gemeric zone (VD2 phase, M1 metamorphism and granitic magmatism), comprising also occurrences in the South Veporic zone, while in the Late Cretaceous time dominantly in the Veporic zone. This can be explained by the different vergencies during the Variscan and Paleo-Alpine orogenies: the Variscan orogeny (incl. thrusting, nappe piling, etc., with related thermal consequences; VD1 deformation phase) was south-vergent, but during the Paleo-Alpine (Cretaceous) orogeny it was north-vergent (AD1 phase). Consequently in the case of terminating Variscan orogeny the Paleo-Tatric-Veporic lithospheric slice was thrust over the Paleo-Gemeric one, followed by the Permian metamorphic core complex formation (metamorphic overprint M1). The Late Cretaceous opposite geometry was applied to north-vergent thrusting, which caused the burial of (at least) South-Veporic zone beneath the overthrust Gemericum (and further superficial nappes). The originating metamorphic core complex in Veporic zone (metamorphism M2) has produced new mineralization. Therefore the ore veins in Gemericum are dominantly Permian in age (with possible weak rejuvenation/remobilization in the Late Cretaceous), but the Late Cretaceous metallogenetic processes are preferably located in the South-Veporic exhumation shear zones.

Within the Gemeric unit, the zonality of Early Paleozoic exhalative-sedimentary (stratabound) mineralization, Permian vein mineralization, stratabound (metasomatic) Fe-carbonate mineralization, magmatogenic Permian granite-related Sn–W mineralization, as well as metasomatic Mg-carbonate mineralization is very distinct, though the course of zones is often disrupted by younger Alpine age tectonics (deformation phases AD1–4).

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Lithostratigraphic units of the Tsetserleg accretionary terrane: New geochemical and geochronological evidences (Central Mongolia)

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Tsetserleg accretionary terrane is one of the several tectonic units in the Khangay-Khentey Fold Belt. The Tsetserleg terrane is composed of Middle Silurian–Upper Devonian oceanic plate stratigraphic sequence (Erdenetsogt formation), Upper Devonian–Lower Carboniferous turbidite (Tsetserleg formation), Lower Carboniferous turbidite (Dzargalant formation) and Lower–Upper Carboniferous flyshoid (Tsoroidog formation) complexes.

The Erdenetsogt formation (S_2–D_2er) consists of various basaltic and upward siliceous (chert) rocks within the several tectonic sheets, which is divided into three subunits. The lower subunit is characterized by greenschist facies metamorphosed basalts and white, white-grey color quartzite, which is Middle–Upper Silurian age as radiolarian fauna, middle subunit is composed of various composition basalt and reddish color chert–quartzite, which is Lower–Middle Devonian, and upper subunit is represented by red color cherts, which contain Middle–Upper Devonian radiolarian fauna. The lower subunit is tectonically overlaid on the youngest subunits.

Volcanic rocks of the Erdenetsogt formation (S_2–D_2er) are subdivided into two types. First affinity is E-MORB, and another affinity is N-MORB.

Upper Devonian–Lower Carboniferous Tsetserleg formation (D_3–C_1cc) is composed of blue, bluish-grey color rhythmic sandstone, siltstone, sometimes thin-layers of conglomerate. Authors dated detrital zircon from the sandstone in the Tsetserleg formation, mean peak is subdivided to I) 2.5–1.7 Ga (n = 13), II) 499–455 Ma (n = 6), III) 382–337 Ma (n =13) and IV) 250–236 Ma (n = 5). We regard that the third main peak can indicate depositional period, because of the fourth peak is related to reaction of metamorphism derived from the Khangay intrusion complex (P_2–T_1) or weathering.

Lower Carboniferous Dzargalant formation (C_1dz) is composed of polymictic and oligiomyctic composition conglomerate, gravelite, coarse-medium grain sandstone, and siltstone. This kind of turbidite lithology is completely different than Tsetserleg Formation. Depositional period of the Dzargalant formation is assigned by paleontological remains (brachiopod): *Neosspirifer sp, Gemulicosta sp, Dengalusia sp, Lanipustula sp.*, *bryozoans*: *Penneretepora sp., Rhombopord sp., Reteporina sp., Sulcoretepora sp.*, Rhabdomesida. These faunas indicate the Visean stage.

The Lower–Upper Carboniferous Tsoroidog formation ($C_{1–2}$cr) consists of thin-thick sandstone with some layers of conglomerate, upward mudstone, slate, thick siliceous slate. In pervious literature, this formation was mapped in Middle-Upper Devonian age. Based on the geochronological dating, depositional peaks of the Tsoroidog formation ($C_{1–2}$cr) are divided into six subgroups: I) 2.8–0.85 Ga (7%), II) 509–448 Ma (18%), III) 439–420 Ma (14%), IV) 414–364 Ma (15%), V) 360–323 (26%), and VI) 323-300 (19%). We regard that the sixth peak can indicate depositional period, because their detrital zircon morphology is well preserved and none of any metamorphic reaction and deformation on the CL images.

Based on lithostratigraphic analysis and geochronological dating, we regard to renewal classify above-mentioned main four units within the Tsetserleg accretionary terrane. In addition, we especially classify the Erdenetsogt formation (S_2–$D_{2(3?)}$er) by the theory of "Oceanic Plate Stratigraphy", and age interval of this formation is long-time scale as Middle Silurian–Middle Devonian.

We provide following geodynamic modelling: The Tsetserleg terrane is one part of Mongol-Okhotsk Oceanic plate, which terrane is newly opened within the intra-arc basin (S_2?) by the processing of delamination, and normally evolved until end of Middle Devonian ($D_{2(3?)}$) as likely oceanic plate. The Tsetserleg terrane is started to accrete under Baidrag microcontinent in Later Devonian-Early Carboniferous (Upper Famennian–Tournaisian) time. Accretion of the terrane is continued during the Carboniferous period.

The Tsetserleg accretion terrane is unconformity overlaid by Lower–Middle Permian sedimentary units with some layers of coal.

Character of fluids from quartz veins of the southern part of the Třebíč Pluton and Moravian Moldanubicum

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Character of the fluid inclusions contributes to understanding of hydrothermal systems evolution. Eight samples of quartz were collected in total from veins in durbachites of southern part of the Třebíč Pluton and migmatites of the Moravian Moldanubicum east of the Třebíč Pluton to reveal conditions of origin of hydrothermal infill of brittle structures in area. Six samples represented hydrothermal quartz veins related to dislocations of various orientation, two samples were pegmatoid vein. Reference sample of quartz–amethyst vein from northern part of the Třebíč Pluton (Bochovice) was added to dataset.

Primary, pseudosecondary and secondary inclusions were observed in almost all samples. Two samples contained only primary (pseudosecondary) inclusions. Size of inclusions were usually from 10 to 25 µm. Shapes varied from regular (negative crystal form and rounded shapes) to entirely irregular inclusions. According to phase composition, five types of inclusions were distinguished in total – V (vapour), L (liquid), L + V (liquid + vapour), $L_1 + L_2$ (two immiscible liquids) and $L_1 + L_2 + V$ (two immiscible liquids + vapour). Two-phase (L+V) and three-phase ($L_1 + L_2 + V$) inclusions were most common. Degree of fill (ratio between liquid and vapour phase) was similar in two-phase inclusions and vapour bubble occupied 5–30 vol. %.

Several chemically different types of fluids were distinguished according to microthermometry measurement:

- H_2O – NaCl – six samples, primary and secondary
- H_2O – Mg ± Na ± K ± Fe chlorides – three samples, primary and secondary
- H_2O – Na ± Mg ± K contained also CO_2 ± CH_4 (up to 4 mol. %) – three samples, primary
- CO_2 ± CH_4 – two samples, primary, maybe also secondary
- H_2O – three samples, primary and secondary
- H_2O – $CaCl_2$ – one sample, secondary

Temperatures of homogenization of primary inclusions varied between 132–375°C. Secondary inclusions usually had lower temperatures of homogenization and they varied in range of 82–220°C. The highest frequency of homogenization temperatures varied between 140–200°C, what are temperatures for common hydrothermal systems (e.g. Wilkinson 2001).

Systems H_2O – NaCl and H_2O – NaCl – CO_2 showed salinities to 8 wt. % NaCl eq. Aqueous solution with prevailing $MgCl_2$ had salinity up to 12 wt. % NaCl eq. System H_2O – $CaCl_2$ had salinity around 16 wt. % NaCl eq. Diagram T_h–salinity (Fig. 1) shows temperature of homogenization and salinity combined together for each inclusion with aqueous solution.

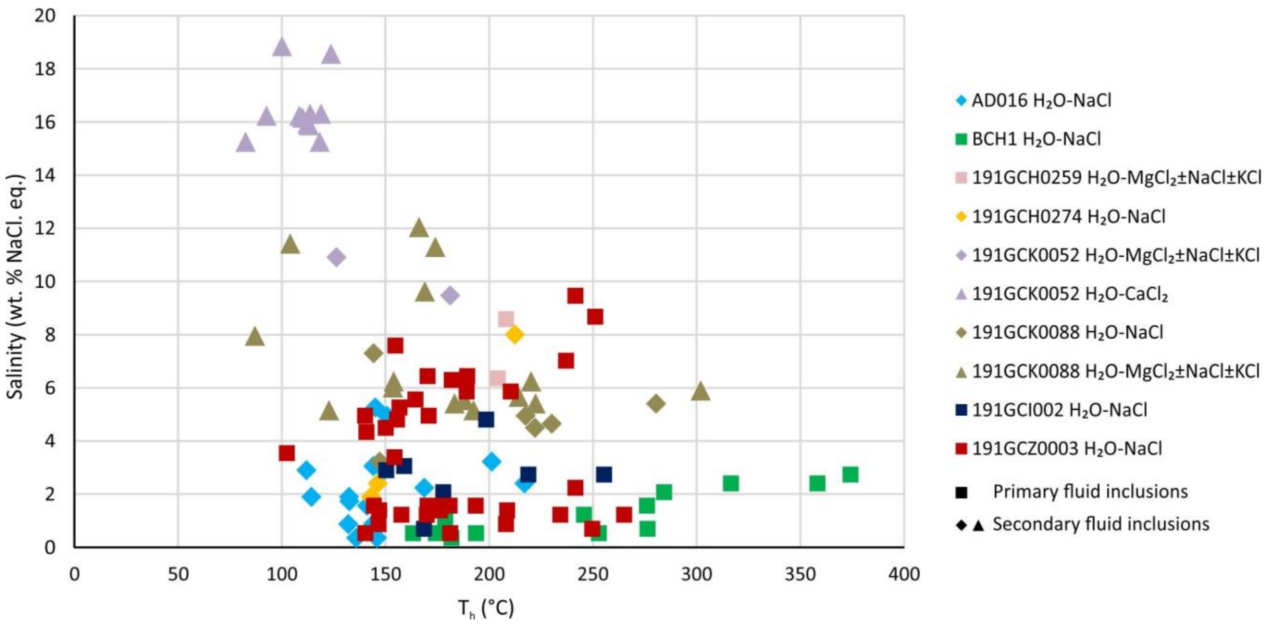

Fig. 1. T_h–salinity diagram included only fluid inclusions with aqueous solutions.

Quartz veins on dislocations originated from low salinity and moderate temperature hydrothermal fluids. Pegmatoid veins were accompanied by low salinity and moderate temperature fluids during their origin. Low temperature fluids in secondary inclusions document cooling of the whole system. System H_2O-NaCl is generally most widespread in hydrothermal fluids. No meaningful differences in temperature were found in hydrothermal quartz from the Třebíč Pluton and Moldanubicum. Mg–K–Fe–chlorides dominated in fluid inclusions from hydrothermal and pegmatiod veins from durbachite. Presence of Mg–K–Fe–chlorides can reflect the chemical composition of the Třebíč Pluton. Carbon dioxide is a common volatile magma component, when comes to its accumulation in the closing phase of crystallization. Bochovice amethyst differs from all other studied samples by higher temperature of homogenization. This supports statement of Mrázek and Rejl (1991) that it is going about a high temperature mineralization.

Acknowledgments
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Deformation microstructures and crystallographic orientation analysis of marbles from the Bôrka nappe, Meliaticum, Western Carpathians

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We present data from microstructural analysis of carbonate rocks, mostly marbles from the Meliaticum Superunit. The Meliaticum as the tectonic unit of the Internal Western Carpathians incorporates the blueschists-facies Bôrka nappe and the low-grade polygenous mélange – Meliata Unit s.s. The Bôrka nappe differs by its relatively high-pressure (HP–LT) metamorphism from the underlying Gemericum and overlying cover nappes of the Turnaicum and Silicicum. The Bôrka nappe forms a complicated structure of slices and klippen partially imbricated with low-grade mélange complexes. Our study is focused on crystallographic orientation of coarse-grained limestones or marbles using the electron backscatter diffraction (EBSD) analysis of monocrystalline calcitic rocks. Samples were collected from various Meliatic complexes, either from the marble formations (Bôrka nappe) or the olistostrome bodies in Jurassic oceanic sediments that contain limestone olistoliths (Meliaticum s.s.). The analysed samples show differences in deformation microstructures, which were used to divide them into three main groups G1–G3. With few exceptions, the distinguished groups approximately match with their regional occurrence. The first group (G1) contains relatively big calcite grains with their typical ‘puzzle’ grain boundary structure. The second group G2 is again relatively coarse grained and shows an onset of dynamic recrystallization where the big calcite grains are partially replaced by the newly formed fine-grained calcite. The G2 group represents a transitional member between G1 and G3 groups. The third group (G3) shows completely recrystallized fine-grained calcite matrix with rare occurrence of the primary calcite porphyroclasts. Marbles of G3 group show a relatively uniform grain size with sharp grain boundaries. Selected marble samples were analysed by EBSD. Data from EBSD were subsequently processed in MTEX Matlab toolbox to obtain information about microstructures, grain size, shape preferred orientation and mainly crystal preferred orientation (CPO). The CPO allowed us to correct the stretching direction in cases where it differed from the macroscopic lineation as well as to resolve the shear sense during deformation of these rocks. Based on macrostructural, microstructural and CPO characteristics the group G3 records deformation in the vicinity of the Veporic unit in the west. Group G1 represent typical occurrences of Bôrka Nappe in the eastern part of study area and samples of group G2 are transitional member between east and west occurrences.

Acknowledgments
The presented data were collected in the frame cooperation with Institute of Petrology and Structural Geology, Charles University, Prague. Financial support from the Erasmus network and from the Grant Agency for Science, Slovakia (project VEGA 1/0085/17) is gratefully acknowledged.

Progressive deformation of Menilite Beds; a case study from the Skole Nappe, Outer Carpathians (Poland)

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In this presentation we discuss the tectonic small-scale structures observed in the exposure of Oligocene flysch strata within the core of Witryłów Antycline in the outermost part of the Outer Carpathian accretionary prism which is the Skole Nappe. The studied part of the nappe consists of NE-verging folds formed due to folding around an NW–SE oriented axis and cut by NW–SE striking thrusts.

The studied exposure shows cherts intercalated by sandstones and mudstones of the lower part of Menilite Beds underlain by Kliwa sandstones. The discussed strata are tightly folded into several NW–SE striking similar folds, verging north–eastwards. Five groups of small-scale structures cut the strata: (i) joints, (ii) thrusts, (iii) clastic dykes, (iv) joints cutting dykes and, (v) fault.

The limbs of discussed folds display two sets of bedding-perpendicular, orthogonal joints (L and T), striking NW–SE and NE–SW, respectively. In fold hinges, radial joints are observed. The folds are cut by NE verging thrusts and clastic dykes, striking sub-parallel to the strike of the bedding. Dykes are irregular in shape, their thickness and dip changes in the observed cross–sections but in general, they are sub-parallel to the axial planes of folds.

In one place a sill branching from a dyke was observed. The sill intruded upwards between layers of host strata. All dykes are cut by joints of two sets which are perpendicular to each other and to dykes walls as well as they are perpendicular and parallel to the dykes strike.

One of the dykes is cut by a thrust striking NW–SE, whereas one sub-vertical fault cuts both folds and dykes. Folding of the host strata, emplacement of dykes, thrusting and jointing took place in the same stress field due to SW–NE oriented compression. The orientation of the dykes indicates that the mobilized material intruded into preexisting thrusts which cut the already indurated and folded Menilite Beds.

Summing up, the discussed dykes intruded along preexisting thrust surfaces into already indurated and folded host strata. Thrusting and faulting persisted after the termination of dyke emplacement. It follows that in the discussed (outermost) part of the Outer Carpathian accretionary prism, thrusting and faulting persisted after the termination of regional folding.

Acknowledgments
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Deep contact of the Bohemian Massif and Western Carpathians as seen from density modelling

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Density modelling was carried out along five profiles oriented across expected deep contact between the Bohemian Massif and the Internal Western Carpathians in western Slovakia. The density models reveal the continuation of the Bohemian Massif beneath the External and Internal Western Carpathians tectonic units. The eastern margin of the Bohemian Massif is situated at depth southeast of the surface outcrops of the Pieniny Klippen Belt and changes its position in the surveyed area.

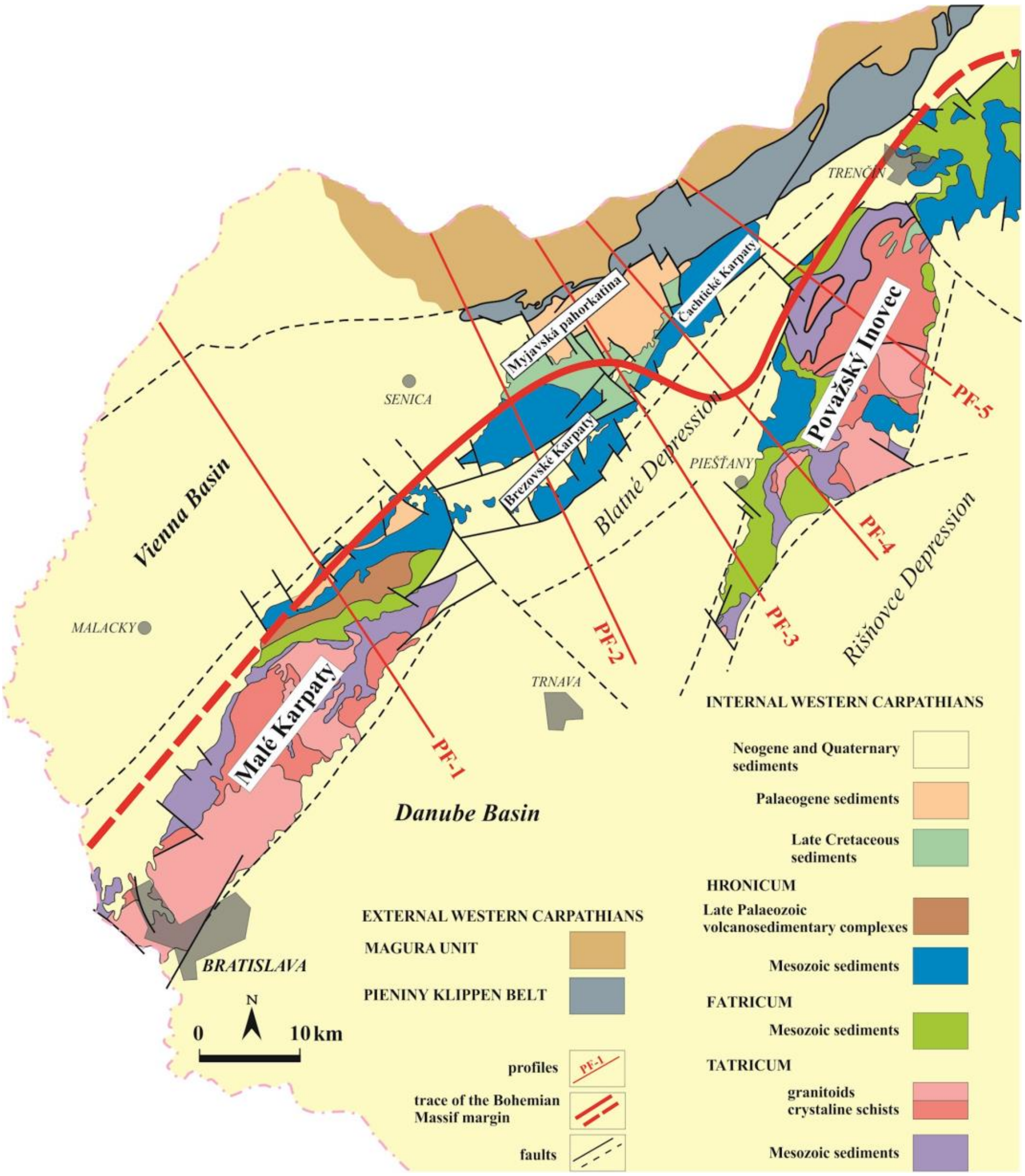

Fig. 1. Trace of the Bohemian Massif margin in a simplified tectonic map.

The contact of the Internal Western Carpathians with the Bohemian Massif and External Western Carpathians is subvertical. This sharp contact is manifested as the transtension to extension zone towards the surface. The surface projection of the contact between the Bohemian Massif margin and the Internal Western Carpathians basement is bent to the southeast (Fig. 1).

Acknowledgments
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Gravity pattern of the Třebíč and Jihlava plutons

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The Třebíč pluton and the Jihlava pluton show non-uniform patterns in gravity maps. This is caused by different densities of the individual pluton segments, as well as by density diversities of surrounding Moldanubian and Moravian metamorphite units. The Třebíč fault and the Kamenice line are the two main lines delimiting different density parts of the Třebíč and Jihlava plutons (Fig. 1).

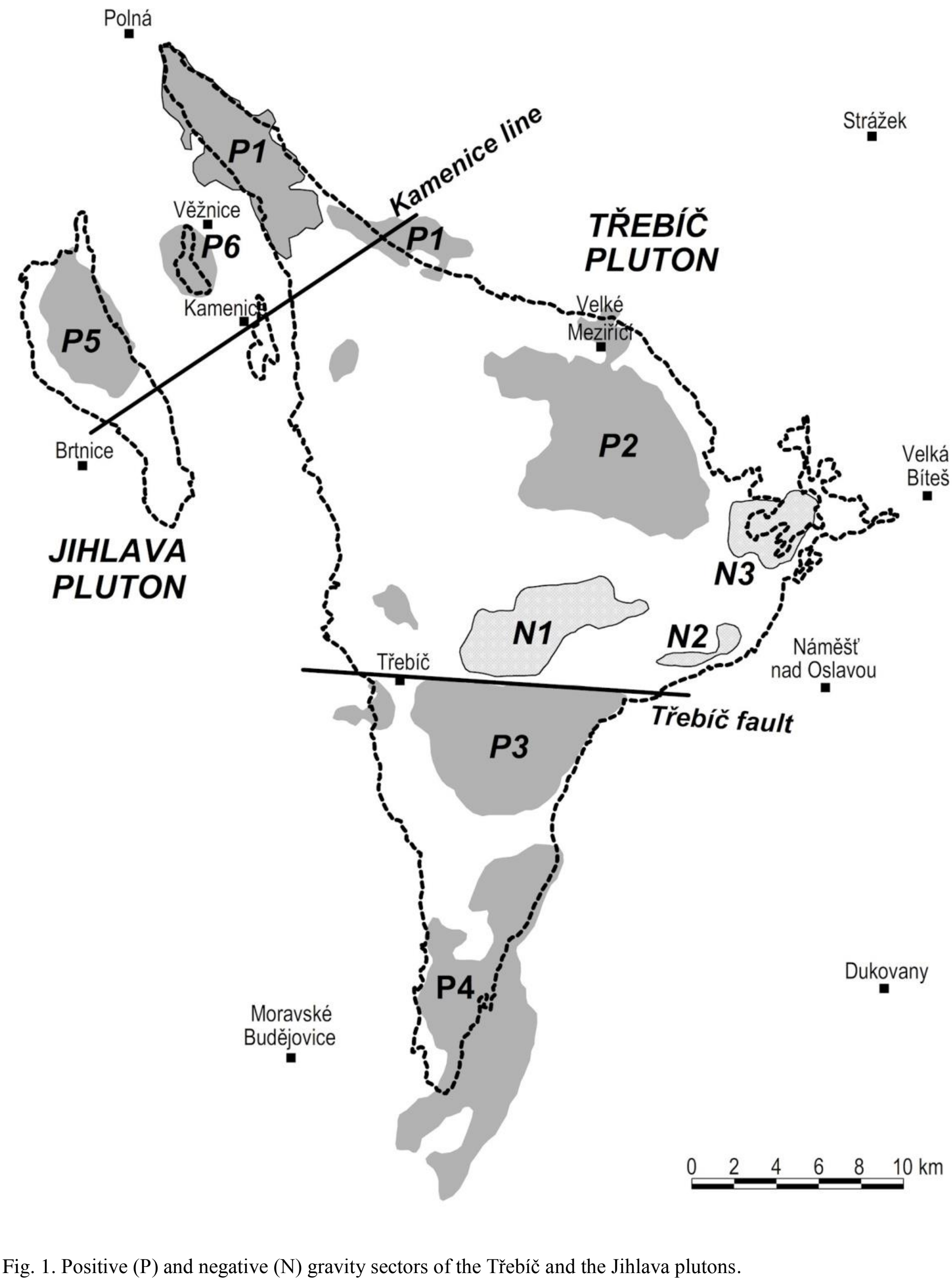

Fig. 1. Positive (P) and negative (N) gravity sectors of the Třebíč and the Jihlava plutons.

Melanocratic durbachites in the NW promontory of the Třebíč pluton (2.75 $g.cm^{-3}$) as well as ultrapotassites of the Jihlava pluton (2.78–2.87 $g.cm^{-3}$) show positive residual gravity anomalies P1, P5, and P6 located to the NW of the Kamenice line. And the dark-coloured durbachite varieties (density 2.72–2.75 $g.cm^{-3}$) in the S promontory of the Třebíč pluton – located to the S of the Třebíč fault – are the source of the positive residual gravity anomalies P3 and P4 round again. The largest middle part of the Třebíč pluton (between Třebíč and Kamenice lines) shows only single positive residual anomaly P2 (situated to the S of Velké Meziříčí). Concurrently, the three negative anomalies N1, N2 and N3 are depicted by rezidual gravity map whitin the eastern margin of the middle part of the Třebíč pluton. They correspond with low density granites, migmatites and aplites (density ~ 2.63 $g.cm^{-3}$). On the other side, no distinct residual gravity anomally occurs to the W of anomalies P2, N1, N2 and N3. There is no meaningful density contrast between the durbachites building up the W sector of the middle part of the Třebíč pluton and the adjoining Moldanubian metamorphic complexes on the W.

Gravity modelling of the Třebíč pluton was carried out by Sedlák et al. (2017). It was found out, that the bottom boundary of the dark-cloured durbachites (2.75 $g.cm^{-3}$) reach the maximum depth of about 2.3 km. And gravity modelling of the high-density ultrapotassic rock in the northern part of the Jihlava pluton (densities 2.78–2.87 $g.cm^{-3}$) revealed the bottom boundary in the depth of 1.7 km.

Acknowledgments
The gravity modelling of the Třebíč pluton and the Jihlava pluton was enabled thanks to SÚRAO.

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Concepts of tectonic evolution of SW margin of the Zavkhan terrane in the Khasagt Mountains (Western Mongolia, CAOB) – review.

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The basement of the SW margin of the Zavkhan terrane (Central Asian Orogenic Belt – CAOB) is best preserved in the Khasagt Mountains in Western Mongolia. Several concepts of tectonic evolution of this part of the Zavkhan terrane have been proposed in last 15 years. Our research focused mainly on cartographic field works and structural analysis of rocks successions of both the Khasagt Zone (autochthonous unit) and the Urgamal Zone (paraautochthonous unit) of the Zavkhan terrane. The petrographic and geochemistry analysis as well as U-Pb SIMS dating were also performed. The preliminary results of the Neoproterozoic-Upper Paleozoic tectonic evolution of the study area were presented in past (Sikora – Wójcik 2017, Sikora et al. 2018), however the newest results of dating (Wójcik et. al. 2019) together with published data (Enkhbaar et al. 2005, Kozakov et al. 2014, Bold et al. 2016, Kilian et al. 2016) allowed to discussion of current concepts.

While all new models share similar tectonic evolution of event related to the Late Baikalian orogeny, the concepts for younger (post-Baikailian) tectonic stages are controversial or incomplete. Generally, our results suggest more complicated tectonic evolution of SW margin of the Zavkhan terrane than it is claimed by the other authors. Most of all we propose a compressional event after emplacements of the Ordovician ryolites (446.03 ± 0.21 Ma, Kilian et al. 2016) of the Teel Formation and the Silurian granites (442.1 ± 19 Ma, Bold et al. 2016) on the west side of the Khasagt Khairkhan Range and before emplacements of the Permian granites (273.7 ± 2.6 to 275.2 ± 5.9 Ma, Wójcik et al. 2019) and ryolites (267.4 ± 3.8 Ma, Wójcik et al. 2019) of the Numrug complex and granite of the Tonkhil complex (286.1 ± 5 Ma, Kilian et al. 2016). The field related structural analysis showed a NE or WSW– ENE directions of thrust faults and duplexes in the clastic Devonian Tsagaan Shoorot Formation. However the sinistral offset structures are locally existing, the dextral directional structures are most frequent in the study area. All these data prove the significant increase of Altai orogeny impact on the structural rebuilding of the Zavkhan terrane.

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Distinction of tectono-metamorphic events in the Variscan Jebilet Massif (Morocco) from structural, petrological and geochronological analyses

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New structural and petrological analyses, coupled with K/Ar geochronological studies are carried out on metapelites from the Jebilet Massif (Morocco) in order to reevaluate the tectonic and metamorphic evolution at the eastern termination of the Alleghanian–Variscan orogen. The absence of oceanic suture and the difficulties in localizing the main deformation front led to the characterization of this zone as an intracontinental orogenic belt within the Gondwana margin. This convergence occurs after an extensional episode leading to the formation of Late Devonian – Carboniferous basins, closely related to the opening of the Paleotethys. In the Jebilet Massif, the difficulty is to discriminate and quantify the deformation and metamorphism related to Visean extension and further Late Carboniferous to Early Permian convergence. Widespread Visean bimodal magmatism controls the development of metamorphism, which in pelitic rocks reaches the Crd–And zone. Pseudosection modeling indicates metamorphism at 540–680°C and 0.6–1.8 kbar. Nevertheless, this hot thermal activity could have continued during Late Carboniferous to Early Permian, i.e during the closure of the basin. Indeed, Bt schists together with late- to post-tectonic garnet and chloritoid are well known in the massif. Furthermore, the timing and quantification of the regional low-grade metamorphism are still unclear and need to be explored, together with the suspect existence of St preserved locally in Crd–And schists. Careful structural analyses seem to indicate two successive convergent episodes of deformation: 1) the first deformation resulted in formation of E–W striking upright folds and the southward stacking of thrust sheets. 2) The second deformation led to refolding of all previous structures by N–S upright folds associated with crenulation axial planar cleavage. To date the metamorphism, we performed preliminary K/Ar datations on fine-grained fractions that provide only Late Carboniferous to Triassic ages. However, the coarse-grained fractions may provide significantly older ages as shown by already published K/Ar ages (Clauer et al. 1980).

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Miocene volcanic rocks in the transitional zone between the Outer Western Carpathians and Bohemian Massif: geochemistry and Sr–Nd–Pb isotopic composition

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Samples covering all petrographic types of the Miocene subvolcanic (dykes, sills) andesitic rock association from the Uherský Brod area (UB, Moravia) in the Czech Republic were studied. The UB volcanic area is associated with the Klippen Zone situated in the neighbourhood of the contact of the Carpathian–Pannonian Block with the Bohemian Massif (Lustrino and Wilson, 2007; Macdonald et al., 2018). Volcanic rocks from the UB area only partly resemble the rocks in a similar structural position in the coeval Pieniny area in Poland (Nejbert et al., 2012). The Miocene volcanic rocks of the Klippen Belt from the UB area form a basaltic–trachytic differentiation series generated by fractional crystallization and magmatic assimilation. Chemical characteristics of this rock series straddle the line dividing alkaline and subalkaline volcanic rocks, while the andesites from the Pieniny area are of calc-alkaline character. The local source of magma in the UB area becomes substantially affected by the metasomatized lithospheric material, generating transitional rocks in a calc-alkaline to alkaline series. The distribution of incompatible elements such as the Nb, Ta, U, Th, ΣREE and La_N/Yb_N ratios as well as the Sr–Nd–Pb isotopic signatures of the andesitic rocks from the UB and Pieniny areas differ substantially. Basaltic–trachytic series from the UB area lack of isotopic component sampled by Miocene andesitic rocks from the Carpathian–Pannonian region and characterised by very high $^{87}Sr/^{86}Sr$ (~ 0.709) and $^{207}Pb/^{204}Pb$ (~ 15.7) initial values (Krmíček et al., in prep.). The mild contents of incompatible trace elements in the andesitic rocks from the Pieniny area correspond mostly to the calc-alkaline characteristics for andesitic rocks from the Carpathian–Pannonian block. Nevertheless, the andesitic rocks from the UB, rich in these elements, resemble (including Sr–Nd–Pb isotopes) the alkaline Miocene volcanic rock series of the Cheb–Domažlice Graben in the Bohemian Massif. Major temperature and pressure ranges calculated for the amphibole phenocrysts crystallization in the andesitic rocks of the UB area are 910–990°C ± 24°C and 0.4–1.2 GPa, corresponding to a depth of ca. 15–45 km.

Acknowledgments
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Lusatian Fault – new geophysical and geological research reveal the evolution of Cretaceous basin in the Saxon-Czech cross-border region.

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The Lusatian Fault represented major tectonic structure more than 100 km long, which is situated alternately on the Saxon and Czech territory. This tectonic zone is associated with two types of faults: normal fault (with dip-slip or strike-slip regime) and thrust fault. The new geophysical survey and subsequent geological work should prove the character of Lusatian Fault in several selected segments. The geophysical methods of electrical profiling and sounding, electrical tomography, reflection seismic and gravity were used in the five localities between Sebnitz, Varnsdorf, Hrádek n. Nisou and Křižany. The geophysical data provide important information for geological interpretation. On the basis of new research the character in individually segments of Lusatian fault zone was determined. In the western part on the Czech territory (between Sebnitz and Varnsdorf) the new geophysical data verified the character of thrust fault, while in the eastern part (between Hrádek n. N. and Křižany) to clearly proved the character of normal fault. Also have been found faults in the NNE–SSW direction crossing the Lusatian Fault that allow the flow of groundwater between Cretaceous sediments in the south and Cenozoic Zittau Basin in the north. The geophysical data enabled precise location of borehole 6412_L that proved the existence of Permian sediments in thickness about 55.5 m over Cretaceous sediments on the Lusatian Overthrust in the Varnsdorf area.

Acknowledgments
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Analysis of marginal fault zone of Blansko trough in Dolní Lhota quarry

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The Blansko trough is the southernmost relic of the Bohemian Cretaceous Basin. The Cretaceous sediments of the trough cover the Cadomian Brno Massif. The tectonic contact between the trough and the massif was the main aim of this contribution. Uncovering of disappearing locality was made on the southwest edge of the sandstone quarry in Dolní Lhota. The fault core is represented by several decimeters thick zone of tectonic clay (219/53). Subsequently ten samples were taken from the fault core to determine direction of tectonic movement by anisotropy of magnetic susceptibility. Resulted AMS-data from samples taken in the locality were plot by Anisoft in azimuthal equal-area Lambert projections on the lower hemisphere (Fig. 1). The longest axes K1 are equal to magnetic lineation. The average orientation of K1 is horizontal in the SW-NE direction (260/0). The shortest axes K3represent poles of magnetic foliation. The average direction of K3 dips under steep angle to the NNW–N (351/59). The middle axes K2 have average orientation of 171/36. The results from the AMS appear to be different in comparison to the values expected from the regional situation. The variance of the results should be explained by the younger deformation along supposed transverse fault comparable to faults observed by Havíř (1998).

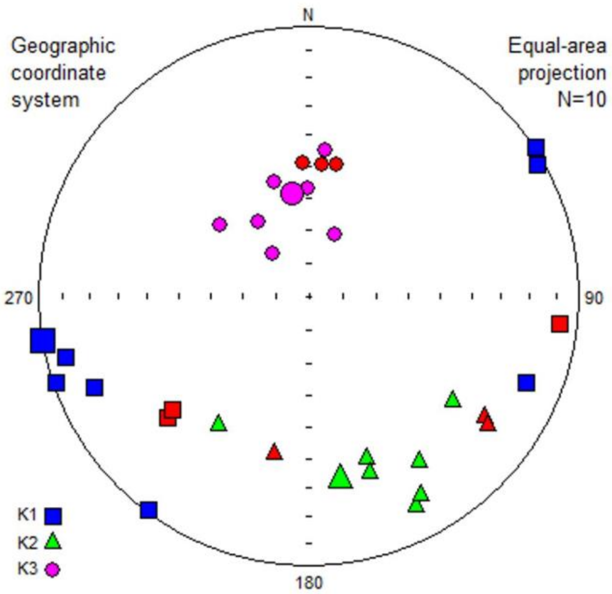

Fig. 1. Orientation of principal axes of AMS. Average values are displayed by the bigger markers.

Early Palaeozoic multi-stage deformational and metamorphic history of the Altai accretionary wedge system (Hovd Zone, western Mongolia)

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The Altai Domain is considered a Cambrian–Ordovician accretionary prism developed during the Palaeo-Pacific subduction (e.g. Jiang et al. 2017). Timing of wedge formation, spatial extent and duration of arc magmatism are relatively well-known (e.g., Broussolle et al. 2019); however, the later tectono-metamorphic crustal evolution remains still partly unresolved. To fill the gap, we studied the high-grade basement of the Hovd Zone (Soejono et al. 2017) at an easternmost periphery of the Altai sedimentary wedge. This area records polyphase deformational and metamorphic history and preserves so far unknown but pivotal structural, petrological and geochronological relationships.

Three tectono-metamorphic events were recognized in the studied metasedimentary and metaigneous rocks. The studied region was characterized by D1 event represented by relicts of small-scale rootless isoclinal folds and earliest relictual MP–MT Barrovian-type metamorphic association (St–Gt) M1 preserved in ubiquitous regional S2 schistosity. The estimated peak conditions of this relictual assemblage are c. 580–600°C and 4–6 kbar. This oldest event was followed by LP–HT metamorphic overprint M2–D2 associated with formation of the penetrative and originally subhorizontal metamorphic fabric S2. This metamorphic reequilibration is represented by association of Crd–Gt–Sill for which peak conditions of c. 650°C and 4 kbar were estimated. Finally, the flat fabric S2 was reworked by largely post-metamorphic D3 deformation resulting in formation of NW–SE trending, tight to isoclinal upright folds with sub-horizontal fold axes.

Laser ablation and chemical U–Th–Pb monazite dating has unambiguously revealed two distinct age groups (Middle Silurian at c. 435 Ma and Middle Devonian at c. 390 Ma). Both ages were obtained exclusively from matrix monazites interpreted as metamorphic based on their shapes, absence of oscillatory zonation and chemistry. We tentatively suggest that there exists a temporal link between the Middle Silurian monazite ages with M1–D1 event and Middle Devonian age with M2–D2 event.

The above structural and metamorphic record, combined with the published metamorphic, magmatic and sedimentary studies from the Altai Domain, suggesting following model of P–T–t–D evolution. The oldest M1 event can be interpreted as a result of moderate crustal thickening of freshly sedimented accretionary wedge in the Middle Silurian. This first metamorphic fabric was reworked by the Middle Devonian horizontal extension associated with elevated heat flux, reported from the several parts of the Altai Domain (e.g. Jiang et al. 2019; Broussolle et al. 2019). The whole system was finally refolded by upright folds during NE–SW shortening in the upper crustal level probably in the Early Carboniferous as indicated by new cooling Ar–Ar ages. The main results of presented P–T–t–D scenario are new age constraints for earliest and latest Early Palaeozoic tectono-metamorphic overprints of the Altai wedge that bracket duration of the Altai orogenic cycle.

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Granite microporosity changes due to fracturing and alteration: secondary mineral phases as proxies for porosity and permeability estimation

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Several alteration facies of fractured Lipnice granite are studied in detail on borehole samples by means of mercury intrusion porosimetry, polarized and fluorescent light microscopy, and microprobe chemical analyses. The goal is to describe the granite void space geometry in the vicinity of fractures with alteration halos and to link specific geometries with simply detectable parameters to facilitate quick estimation of porosity and permeability based on, for example, drill cuttings.

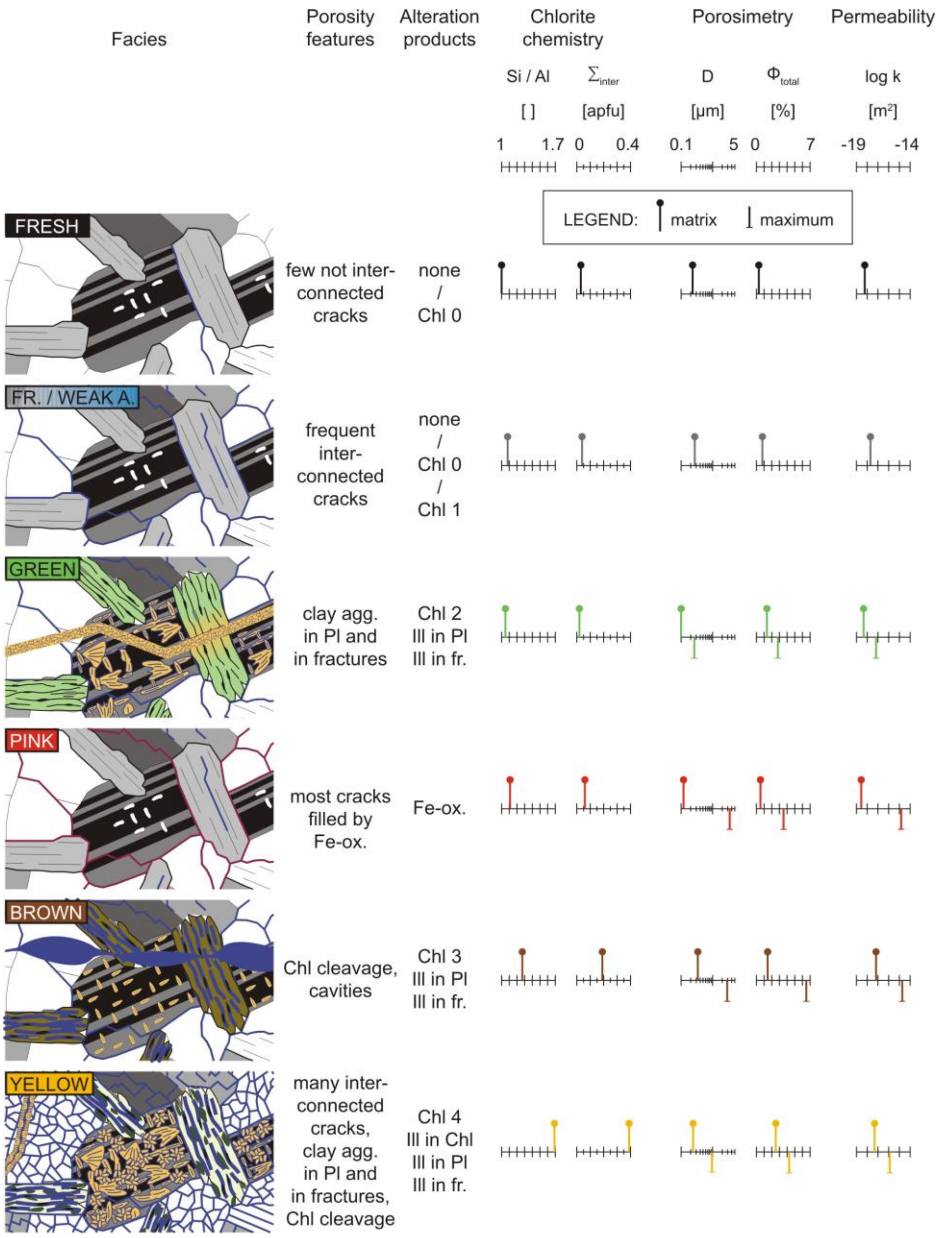

Fig. 1. Synthesis of microstructural, chemical and porosimetric observations. Chl: chlorite, Pl: plagioclase, Ill: illite, Fe-ox.: iron oxides, fr.: fractured, a.: altered, agg.: aggregates, $\sum_{inter}$: sum of interlayer cations (K, Na, Ca), D: volumetric median throat size, Φ: porosity, k: permeability and apfu: atoms per formula unit.

The core of the study is the results of porosity and throat size distribution analyses on 21 specimens representing unique combinations of fracture-related structures within six different alteration facies basically differing in secondary phyllosilicate chemistry and porosity structure. Based on a simple model to calculate permeability from the measured porosities and throat size distributions, the difference in permeability between the fresh granite and the most fractured and altered granite is 5 orders of magnitude.

Our observations suggest that the porosity, the size of connections and the proportion of crack porosity increase with fracture density, while precipitation of iron-rich infills as well as of fine-grained secondary phyllosilicates acts in the opposite way. Different styles and intensities of such end-member agents shape the final void space geometry and imply various combinations of storage, transport and retardation capacity for specific structures. This study also shows the possibility to use standard mercury intrusion porosimetry with advanced experimental settings and data treatment to distinguish important differences in void space geometry within a span of a few percent of porosity.

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Monazite dating of prograde and retrograde P−T−d paths (the Thaya and Svratka windows, Bohemian Massif)

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Monazite laser ablation–split-stream inductively coupled plasma–mass spectrometry (LASS) was used to date monazite in situ in Barrovian-type micaschists of the Moravian zone in the Thaya and Svratka windows, Bohemian Massif. Petrography and garnet zoning combined with pseudosection modelling show that rocks from staurolite–chlorite, staurolite, kyanite and kyanite–sillimanite zones record burial in the S1 fabric under a moderate geothermal gradient from ~ 530–540°C and 4–4.5 kbar to 5 kbar/570°C, 6−7 kbar/600−640°C, 7.5−8 kbar/630−650°C, 8 kbar/650°C, respectively. In the kyanite and kyanite–sillimanite zones, garnet rim chemistry and local syntectonic replacement of garnet by sillimanite–biotite aggregates points to reequilibration at 5.5−6 kbar and 630−650°C in the S2 fabric. Heterogeneously developed retrograde shear zones (S3) are marked by widespread chloritization, but minor chlorite is present in the studied samples. Monazite abundance and size increase with metamorphic grade from 5 μm in the staurolite–chlorite zone to > 100 μm in the kyanite and kyanite–sillimanite zones. Irrespective of the monazite-forming reaction, this is interpreted as the onset of limited prograde monazite growth at staurolite grade, and continued prograde monazite growth after the kyanite-in reaction, compatible with conditions of about 5.5 kbar/570°C, 7.5 kbar/630°C from pseudosection modelling. Monazite is zoned, showing embayments and sharp boundaries between zones, with low Y in the staurolite zone, high-Y cores and low-Y rims in the kyanite zone, and high-Y cores, a low-Y mantle and a high-Y rim in the sillimanite zone. The ^{207}Pb-corrected ^{238}U/^{206}Pb ages range from 344 ± 7 Ma to 330 ± 7 Ma, irrespective of metamorphic grade. The dates from monazite inclusions are interpreted as the ages of the staurolite and kyanite-in reactions along the prograde path at 340 and 337 ± 7 Ma, respectively. The monazite in the matrix (and some inclusions) are interpreted as dating the prograde crystallization at 340−337 ± 7 Ma within the S1 fabric, and then affected by recrystallization at/or down to 332 ± 7 Ma in the S2 and S3 fabrics. The two groups of data, 340−337 Ma and 332 Ma, are significantly different when only their in-run uncertainties (± 1–3 Myr) are compared and indicate a 9 ± 3 Myr period of monazite (re)crystallization. A systematic increase in HREE content with decreasing monazite age from 344 to 335 Ma is correlated with the growth on prograde P−T path, a drop in HREE of monazite at 335−328 Ma is assigned to recrystallization. The presence of chlorite even in the least-retrogressed samples witnesses limited external fluid availability on the retrograde P–T path. Migration of this fluid was likely responsible for heterogeneous fluid-assisted recrystallization and resetting of original prograde monazite, even where included in garnet, staurolite or kyanite. It is suggested that the rocks passed the chlorite-in reaction on the retrograde path at 332 ± 7 Ma. The timing of burial in the deformed part of the underthrust Brunia microcontinent was coeval with exhumation of granulites and migmatites of the Moldanubian orogenic root at c. 340 Ma.

The Higher Himalaya Crystalline migmatites in Zanskar are exhumed along compressional vertical fabric followed by extension

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The migmatites of the High Himalayan Crystalline (HHC) are supposed to be exhumed during simultaneous operation of the extensional South Tibetan Detachment System (STDS) at the top of the HHC and thrusting of the HHC along the Main Central Thrust over the Lesser Himalayan sequence. In the Zanskar mountain range, NW India, the Zanskar shear zone is the expression of the STDS. There, the migmatites occur less than 1 km from the greenschist-facies rocks of the Phe formation, and are separated by garnet, staurolite and kyanite schists. This extremely thinned thermal structure is classically thought to be the result of extension. We reexamined the area of the Gumburanjon domain. Here, the first foliation is a NE−SW trending subvertical fabric, which is greenschist-facies in the Phe fm., solid-state in the garnet, staurolite and kyanite zones, and anatectic in the migmatite zone. The S1 fabric is folded by F2 folds with NE-dipping axis and NE-dipping axial plane in the garnet to migmatite zone where it leads in places to almost complete transposition. In the Phe fm. the D2 deformation is very locally developed as a NE-dipping cleavage localized in pelitic layers and more rarely as F2 folds geometrically correlated with higher-grade rocks. Under the microscope, the steep fabric is characterized by cleavage marked by fine grained white mica and chlorite in the Phe fm. and by and alternation of mica- and quartz-rich bands in metasediments together with inclusion trails within porphyroblasts and shape preferred orientation of garnet, staurolite and kyanite. In metasedimentary migmatites, the steep fabric is marked by orientation of leucosomes, mica-rich bands, inclusion trails within garnet and by shape preferred orientation of kyanite. The peak P–T conditions achieved within the S1 fabric are greenschist, 600°C/7 kbar; 650°C/9 kbar, 750°C/10 kbar for the Phe fm; staurolite, kyanite and ky-migmatite, respectively. The S2 cleavage is in places marked by the growth of andalusite and cordierite in medium and high-grade rocks, indicating exhumation at an elevated geothermal gradient, and explained by numerous leucogranite intrusions parallel to S2. The inferred P−T−D paths indicate at first a vertical stratification with normal thermal structure from greenschist to migmatite contemporaneous with vertical NE−SW trending foliation. This stage is followed by extrusion of the migmatite through the upper crustal levels parallel to the vertical fabric. The last stage is the F2 folding with development of the S2 cleavage. The thinning of the isograds happens already during the vertical structure development, related to vertical extrusion. It is accentuated by the vertical shortening that leads to folding of the S1 foliation but also causes folding of the original S1 isograds. The Gumburanjon domain is thus interpreted as a low strain domain which is not completely overprinted by the extensional S2 shearing of the STDS. This low strain domain preserves subvertical structure from greenschist-facies superstructure to migmatitic infrastructure and indicates that the lower-crustal kyanite migmatites were exhumed vertically during compression close to garnet zone, a process not so-far reported in the area of STDS.

Do deformation bands record the early onset of backthrusting? Insights from the inner part of the Silesian Nappe (Outer Western Carpathians, Poland)

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The objective of this study is to present the record of deformation bands (DB) in a regional overthrust and its implications for the structural history of the Silesian Nappe.

The Silesian Nappe is one of the nappes within the Outer Carpathian orogenic wedge. In the Polish segment of the Outer Carpathians, its easternmost part is subdivided into the Fore-Dukla Zone (inner part) and the Central Carpathian Synclinorium (outer part). The contact between the discussed tectonic units has a tectonic origin and in most papers is interpreted as a backthrust. The general strike of regional scale structures in discussed area shows NW–SE trend. The contact was studied along the Solinka River, in the vicinity of Dołżyca village.

Two sites abundant in DB were examined, both localized in the hinterlandward part of the Central Carpathian Synclinorium, within thick-bedded sandstones in the hanging wall of the backthrust. The first site (River site) is located directly in the frontal part of the main backthrust (Fig. 1).

There, strata of the lower member of the Lower Krosno beds dips ca. 40° to the NE in normal stratigraphic position. In this site, the DB show weak cataclasis, reverse sense of slip and parallel arrangement to the bedding strike. The origin of these DB could be linked to backthrusting. The second site (Quarry site) is located 500 meters to the NE from the backthrust within the upper member of the Lower Krosno Beds. In the quarry, the strata dips ca. 40° to the NE as well but in an overturned position. In this site normal sense slip, conjugating two sets of DB, were observed. The DB originated exclusively due to granular flow and, similarly, they are arranged parallel to the bedding strike. Moreover, slip surfaces cutting DB developed on bed planes were observed. Restoration of the strata to their primary stratigraphic position suggests that DB were developed prior to folding due to the SW–NE extension. Thus, slip surface on the bedding planes probably developed either due to flexural slip during folding or to gravitational sliding (cf. Kuśmierek 1979). Granular flow within DB indicates shallow burial conditions and poor consolidation of the host strata, while cataclasis indicates more advanced strata induration and usually greater burial depths (Fossen et al. 2007). Therefore, the different inner structure of studied DB in the particular sites might be related to the different age of the host strata. Nevertheless, DB in both sites were formed early, when the host strata were poorly indurated. This implies the presence of early vertical stress state zonation within the Lower Krosno beds. Such a situation can occur when the developing thrust fault involves local uplift and, accordingly, extension in the uppermost part of an orogenic wedge (cf. Azevedo et al. 2018). It follows that studied backthrust began to form shortly after deposition of the upper member of the Lower Krosno beds while the strata were not yet fully indurated, possibly during late Oligocene/early Miocene? times.

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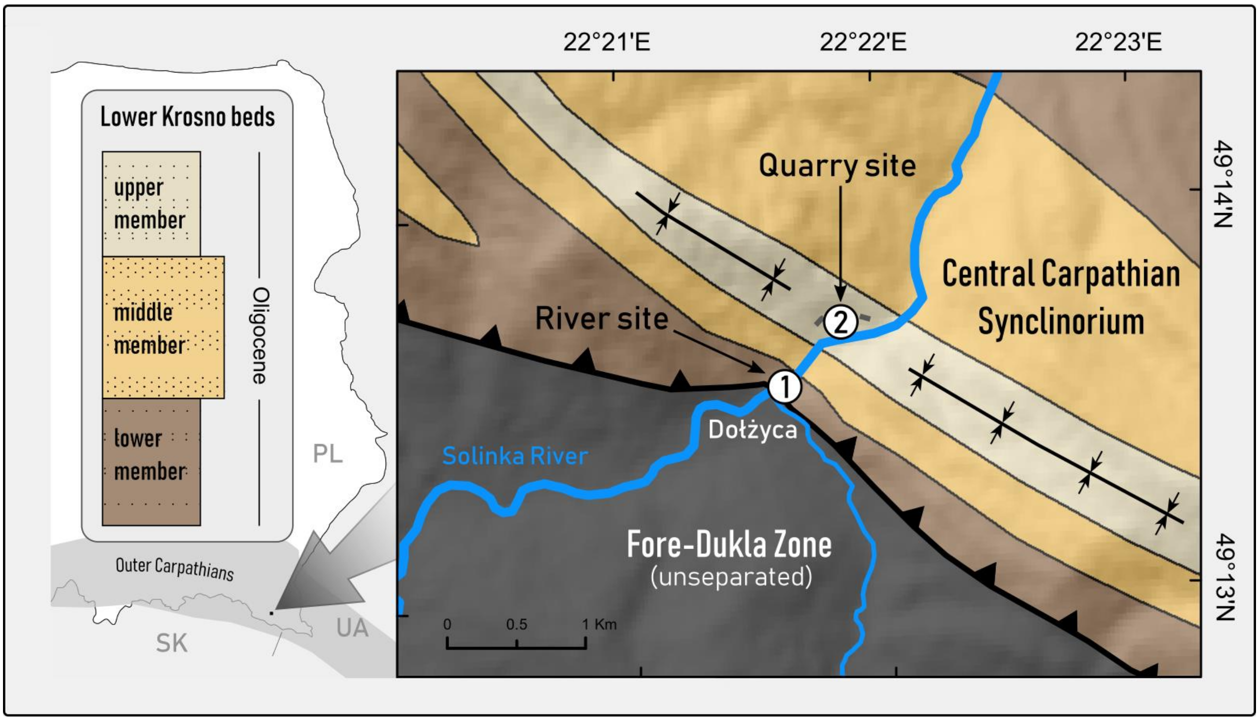

Fig. 1. Simplified geological map of the studied section (modified after Ślączka – Żytko 1978).

The internal architecture of the Early Paleozoic accretionary prism, Tseel unit, southern Mongolia – new geochronological, structural and petrological constraints

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The Tseel unit in the Mongolian Altai zone is a part of the large Cambrian–Ordovician accretionary system extending approximately 2,000 km from Russia to Mongolia and representing one of the critical elements for reconstructing early Paleozoic geodynamics of the Central Asian Orogenic Belt (CAOB). The studied area is dominated by a strongly deformed succession of low- and high-grade metasedimentary rocks characterised by dominant terrigenous components mixed with volcanogenic material. The studied section could be divided to three distinct domains with the newly contrasting metamorphic, structural and geochronological record. The northernmost part of the studied area is dominated by volcano-sedimentary sequences affected by Barrovian-type metamorphism manifested by garnet to kyanite bearing assemblages in pelitic rocks. The dominant metamorphic fabric S1 is NE–SW trending and is affected by upright folding under greenschist facies conditions. The dominant age of detrital zircons spans from ca. 539–445 Ma indicating Early Paleozoic age of sediments, while narrows metamorphic zircons reveal ages from ca. 430–393 Ma suggesting Late Silurian – Early Devonian age of high-grade metamorphism. The central part of the studied section reaches high-temperature conditions manifested by partial melting and large abundance of S-type granites in its southern and structurally deepest part. This part shows a progressive increase in the intensity of superposed deformation and development of sub-horizontal metamorphic foliation S2. This metamorphic foliation is affected by late upright folding accompanied with the development of ENE–WSW trending shear zones. The zircon ages show inheritance of both above-mentioned populations with the addition of newly-formed zircons in migmatites and granites of Early to Late Devonian age (ca. 388–359 Ma). The southernmost part of the studied section is lithologically distinct and structurally most complex. It is dominated by dark greywackes affected by very high-temperature (granulite facies) metamorphism. The refractory rocks exhibit similar zircon populations like the central part of the section with a slightly older range of Cambro-Ordovician population (ca. 539–460 Ma). In contrast, the more fertile migmatitic rocks are dominated by zircons that show Late Carboniferous – Permian ages (ca. 269–300 Ma). These distinct geochronological records spatially coincide with the distinct structural record, suggesting localised vertical extrusion of deeper crustal rocks during Permian convergence.

Cenozoic exhumation and fault activity of the Mariánské Lázně Fault, Czech Republic, from low temperature thermochronology – preliminary results

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The NNW-striking Mariánské Lázně Fault (MLF) in northwestern Bohemia controls the eastern limit of Cheb – Domažlice Graben. It is superimposed on the western part of the NE-trending Eger Graben, which is part of the European Cenozoic Rift System. The Eger Graben contains a Cenozoic volcano-sedimentary record no thicker than 500 m. The main graben structure is delineated by two faults: (1) the ENE-striking Krušné Hory Fault (KHF), which delimits the northwestern shoulder of the Eger rift and has accommodated tilting and uplift of the Krušné Hory (Erzgebirge), creating a present day elevation difference of 700 m and (2) the České Středohoří Fault which separates the basin from the southern rift shoulder. The Mariánské Lázně Fault perpendicularly cross cuts these two faults, forming the boundary to the Cheb Basin, which is a dominant feature of the local topography and is associated with earthquake swarms, voluminous mantle-derived CO_2 outgassing and Quaternary volcanism. Yet despite their importance for the formation of the local topography, the exact time of onset of fault activity, fault offset and total exhumation of the resulting shoulders remains unclear.

We present a new apatite (U–Th)/He dataset (AHe) of a sampling profile crossing the MLF onto the Slavkovský Les Mountains (Kaiserwald), and compare it to previously published vertical transects across the Eger Rift shoulders (Tomasek et al. 2018, Szameitat et al. 2018). Additional information regarding the zero age depth is gained by a second new apatite (U–Th)/He dataset from the Weissenstadt borehole in Germany, approximately 50km west of our study area. It is located in the same basement granites that underlie the Cheb Basin and thus provides a good proxy for exhumation estimates.

Geochemistry, zircon U–Pb and Hf isotopic compositions of lower crustal rocks from the Góry Sowie Massif (Central Sudetes, SW Poland): New insights on the sedimentary origin and tectono-thermal evolution

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Devonian HP–UHP lithotectonic associations represent a pivotal element of Paleozoic evolution of the European Variscan belt across the continent from Portugal to Poland. The Góry Sowie Massif (GSM), located in the Central Sudetes, represents one of the best preserved outcrops of lower crustal rocks that experienced a protracted Devonian tectono-metamorphic history at the easternmost extremity of the belt. The area is surrounded by Devonian ophiolite remnants and Devonian to Carboniferous sedimentary basins in the northern and southern part, respectively. The GSM is mainly composed of paragneisses and subordinate orthogneisses, metabasites and granulite. The dominantly sedimentary association and the overall geotectonic setting contrast with the other km-scale granulite complexes in the Bohemian Massif that are dominated by felsic granulites and late Cambrian orthogneisses that experienced 340 Ma HP metamorphism. Weak Carboniferous overprint makes the GSM a key locality to better understand the Devonian stages of formation of HP granulites and provenance of the whole pre-Devonian lithological association. New U–Pb and Lu/Hf analyses were carried out on zircons from 4 migmatitic paragneisses, 3 felsic biotite-poor granulites and 2 biotite-rich granulites in the northern part of the GSM, and combined with geochemical analyses in order to constrain a source provenance and tectono-thermal history of the area. The paragneisses dominated by stromatic migmatite and felsic granulites occur as hundred meter-scale bodies associated with metric lenses of amphibolites, mafic and ultramafic rocks in the northern part of the massif.

Under CL, zircons from paragneisses and granulites show similar patterns characterized by oscillatory cores (Th/U > 0.1) overgrown by dark homogenous metamorphic rims (Th/U < 0.1). The cores record abundant Cambro–Ordovician population (492–545 Ma) and few Neoarchean to Proterozoic clusters, whereas the metamorphic rims yield younger ages between 381 and 402 Ma. In contrast, zircons from biotite-rich granulites provide a main peak at 499–531 Ma with a small younger cluster at 396–425 Ma and a minor older population at Neoarchean to Proterozoic. The main Cambro–Ordovician zircon populations show either positive εHf values (from 0 to +10) with TDMs between c. 0.68 to 1.2 Ga, pointing to production of juvenile magmas and could be consistent with a magmatic arc setting, or negative εHf values (from 0 to –21) with TDMs between 1.2 and 2.3 Ga, pointing to mixing process between juvenile magmas and Eburnean–Archean crustal component.

Based on classification and tectonic setting discrimination diagrams, the protoliths of granulites and paragneisses are geochemically analogous to graywacke and point to an active continental arc depositional setting dominated by Cambro-Ordovician detritus. The Cambrian sedimentary and possibly also felsic and mafic volcanic rock association was subsequently metamorphosed by a Middle Devonian HP tectono-thermal event coeval with the emplacement of the Devonian ophiolitic rocks surrounding the area. Therefore, the Devonian HP event is possibly related to large scale oceanic/continental subduction.

LA-ICP-MS zircon ages of the Slavkov Terrane, Central Basic Belt and Basal Clastics, Brunovistulicum, Czech Republic

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The Brunovistulian microcontinent extends from Vienna up to the Odra–Cracow Fault and is exposed in particular in the Dyje and Brno batholiths. The latter has been subdivided into the Slavkov and Thaya/Dyje terranes of Neoproterozoic arc-related tonalites, (grano)diorites and granites, and the Central Basic Belt (CBB) separating them. The Slavkov Terrane is for the largest part overlain by Neoproterozoic–Cambrian and younger sediments, of which the lowermost are known as the Basal Clastics and are exposed near Brno as mature red sandstones with conglomerates in their lower parts. In contrast to the Thaya Terrane, crystallization ages for Slavkov Terrane granitoids remained poorly known. We present the LA–ICP-MS zircon dating results for Slavkov Terrane granitoids, a metatuff of the CBB, and for sediments, clasts and felsic tuffs of the Basal Clastics.

The volumetrically important Královo Pole and Blansko type granodiorite and tonalite have pooled zircon ages of 595 ± 1 Ma (Jehnice) and 597 ± 2 Ma (Blansko), and a Doubravice type granodiorite has a 606 ± 2 Ma age (Lhota Rapotina). Diorites from boreholes southeast of Brno have ages of 594 ± 2 Ma (Uhřice 4), 594 ± 4 Ma (Uhřice 5), 596 ± 2 Ma (Ježov 2) and 601 ± 2 Ma (Ždánice 14). Leucogranite from Popice 2 borehole yielded a 590 ± 8 Ma age for cluster of nine 2% concordant zircons. In addition, subvolcanic rhyolites intruding the CBB have ages of 594 ± 3 (Kohoutovice) Ma and 594 ± 2 Ma (Želešice). In contrast, 10 zircons from a generally zircon-poor CBB felsic metatuff near Česká yielded a much older 740 ± 4 Ma age. Two felsic tuffs from the lower part of the Basal Clastics in the Brno area have indistinguishable ages of 551 ± 1 Ma (E of Bílovice nad Svitavou) and 552 ± 2 Ma (Šumbera forest road – Hády hill, Brno). Detrital zircon age spectra for three sandstones show single age peaks around c. 600 Ma (Brno and Babí lom), or around c. 650–660 Ma and c. 558 Ma (Česká). Older Precambrian zircons are rare and Palaeozoic zircons are absent. Granite clasts have protolith crystallization ages of 592 ± 2 and 594 ± 2 Ma (Hády quarry, Brno). A Ms granite clast from E of Bílovice nad Svitavou yielded a younger 558 ± 3 Ma age for a youngest zircon age cluster.

The narrow 590–601 Ma age range for Slavkov Terrane granitoids shows that the main magmatism took place within a short time interval in the Ediacaran and was coeval with that in the Thaya Terrane that has published ages of 568–634 Ma, of which most between c. 580–605 Ma. In contrast with the Thaya Terrane, the dearth of older, inherited ages in Slavkov Terrane granitoids points to a more juvenile origin for the latter. This is in keeping with published models and recent isotope data (Krmíčková et al., this volume) that indicate a continental arc setting for the Thaya Terrane and an oceanic primitive arc setting for the Slavkov Terrane. The 740 ± 4 Ma age for CBB metatuff confirms that the volcanic part of the CBB predates the Slavkov and Thaya terranes by c. 140 Ma. The large age difference and its published MORB-like geochemistry render it unlikely that it constituted the back-arc basin to the Thaya and Slavkov arcs, but instead formed much earlier during break-up of Rodinia. The age data for the Basal Clastics show that deposition occurred around 550 Ma in the late Ediacaran (similar to Baltica), c. 50 Ma after the main plutonism in the arc terranes, and that nearly all material was derived from local sources that must have been exposed in small catchment areas only. Older detrital zircons are rare in the Basal Clastics, but the wide 564 Ma to 3.30 Ga range of detrital zircons from a quartzite and a sandstone clast shows that around 550 Ma, Palaeoproterozoic to Archaean continental crust must have been in erosional position nearby.

Mechanisms of tectonic deformation in the Main Dolomite (Upper Permian) on the Fore-Sudetic Homocline, SW Poland

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The geometry of the Main Dolomite (Ca2) lithosomes, reflects the paleotopography of its depositional areas and shows strong relationship with the morphology and structure of the basin floor, represented by the top-Carboniferous unconformity. The deposition of the Ca2 member has also been affected by the distribution of anhydrite/sulphate platforms of the underlying PZ1 cyclothem of the Zechstein suite. The depositional style of the Ca2 carbonates varied from basin interior environments through the toe of slope and platform slope to sulphate-bearing barriers. Our study focused on the origin of seismic-scale tectonic structures in the Ca2 member and their influence on the distribution of small-scale fractures we studied in the borehole cores from the so called Grotów Peninsula.

The Main Dolomite (Ca2) is a member of the Permo-Mesozoic Polish Basin's Zechstein. The Ca2 is composed of carbonates occurring at the base of PZ2 cyclothem, that corresponds to the Stassfurt cycle of Germany. The Ca2 overlies the Upper Anhydrite (A1) member of the PZ1 cyclothem and is coved by the Basal Anhydrite (A2) and the Older Halite (Na2) members. The Ca2 is mechanically coupled with the both anhydrite layers, creating a relatively competent rock complex, in-between much less dense and more ductile rock salt layers. Such a mechanical sandwich made a perfect setting for buckle folds to develop and for their detachment and compensation to occur within the lower and upper salt layers.

Theoretically, three main mechanisms of Ca2 deformation can be taken into account, and discrimination between them is not always obvious. (1) Formation of extensive submarine landslides is expected to have led to soft-sediment folding at the foot of anhydrite slopes. This mechanism is not expected to have produced brittle fractures. (2) Alteration of gypsum to anhydrite within platforms must have resulted in volumetric contraction of up to 38% and this may have led to disharmonic folding of the Ca2 and to brittle fracturing. (3) Tectonic buckling related to Late Cretaceous-Paleogene compressive inversion of the Mid-Polish Trough may have resulted in development of systematic fractures in brittle dolomite rock. This mechanism of folding faces the problem with propagation of far-field compression along or across ductile salt complexes, which can be the reason of why this kind of folding has only locally developed.

Over the Gorzów Penninsula sets of local folds with amplitudes of 10 to 30 m and wavelengths of 500 to 1000 m are found on seismic sections below the anhydrite platform. The roughly E–W trending fold axes are parallel to an anhydrite barrier in the north; therefore we infer they may have originated from gravitational slides on the platform slope and/or from a tectonic compression, with the slope acting as a buttress. The folds' wavelength increase together with the thickness of the folded competent layer – a feature that is characteristic of buckling mechanism.

In another location, a group of cross-folds with axes perpendicular to the platform slope was interpreted. Their orientation is compatible with their origin due to Late Cretaceous compression. An industrial analysis of seismic data indicates increase of porosity in the hinges of anticlines of this group of folds. We attribute it to a secondary porosity, namely the volume of open fractures.

Above the anhydrite platform, systematic folding and thrusting phenomena in the A3 horizon are apparent on seismics, being compensated within the Na2–K2 salt, and the Ca2 member below, mechanically coupled with the anhydrite platform, is not folded. Deformation structures in the Ca2 are irregular and, genetically, may be attributed to a collapse of the platform. This inference is confirmed by by an increase in percentage of calcite- filled veins in the total number of fractures than that at the foot of the platform. Fractures must have been mostly sealed at an early stage of diagenesis at the time of platform collapse and due to the lack of hydrocarbons that might have preserved the fracture space open.

A number of data corroborates a role of compression in the formation of folds in Ca2, in line with the seismic interpretation. However, due to the lack of borehole scanner/imager logs, the identified fractures can rarely be oriented and leave space for alternative interpretations. We believe that continuation of such studies should contribute to better characterization and understanding of fractured reservoirs and their more efficient exploitation.

Postmagmatic evolution of the Cínovec/Zinnwald granite cupola (Bohemian Massif): is there a genetic relationship of pluton architecture to brittle structures and greisen vein system?

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The Cínovec/Zinnwald granite cupola represents the apical part of a post-collapse pluton emplaced into the Late Carboniferous Altenberg–Teplice caldera in the NW Bohemian Massif. The cupola is vertically zoned and dominated by alkali feldspar A-type granite of the Younger Intrusive Complex (YIC) of the Krušné hory/Erzgebirge batholith. The pluton hosts extensive postmagmatic Li–Sn–W greisen mineralization. Metasomatic quartz–topaz–zinnwaldite greisens occur along fractures or form massive lens-like bodies within the granite. The aim of this study is to analyse brittle structures throughout the cupola and its host Teplice rhyolite (an intracaldera fill), and investigate their relation to the overall pluton architecture and greisen mineralization. We employ detailed structural mapping of veins, greisen lenses, faults and joints in the northern part of the Cínovec/Zinnwald cupola in the mine at Tiefe–Bünau–Stollen (Germany). Our preliminary results distinguish several trends in orientation of structures. The major quartz–topaz–zinnwaldite veins (*Flözen*) and greisen lenses dip shallowly towards NE and strike ~ NW–SE. These veins and greisens continue from inside the cupola away to the host rock and show lateral compositional variations: the major topaz and zinnwaldite vein infill is restricted to the pluton, whereas quartz-only veins occur in the host rock. The low-mineralized subvertical veins (*Morgengänge*) fill ~ NE–SW striking faults with complex kinematics. Several generations of subvertical brittle fractures in the pluton bear two principal orientations: ~ NE–SW and ~ NW–SE. By contrast, fracture pattern in the host Teplice rhyolite includes steep to subvertical ~ NE–SW striking joints and subhorizontal ~ NE dipping joints. The fractures are either barren or are filled by clay minerals, quartz, topaz, hematite, fluorite, calcite, and other mineral species. The thickness usually does not exceed a few millimetres. Kinematic indicators (if present) show mostly sinistral strike-slip to oblique-slip movements. The relationship of these structures to the magmatic pluton architecture and implications for genetic interpretation of postmagmatic processes is the target of ongoing research. The structural data will be plotted in an ArcMap environment as an input for a 3D model of the Cínovec/Zinnwald granite cupola constructed using the advanced modelling software LeapFrog.

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Shear strain and volume change estimation in shear zones using sigmoidal extension veins

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The Permian Boda Claystone Formation (BCF) in the Mecsek Mts, SW Hungary is a potential host rock of the high-level nuclear waste repository in Hungary. The rock body is intensely fractured; typical brittle structures are the sigmoidal tension gash arrays occur along shear zones. These structural elements can be used to determine the shear strain and the volume change of the shear zones with various methods. Morphological, mineralogical, mass balance and micro CT analyses were carried out on samples from the BAF–2 well to estimate the shear strain and the volume change of the shear zones. Along the borehole over 200 sigmoidal tension gash arrays were detected. The dominant vein-filling mineral is fibrous calcite, with small amount of barite, celestine and anhydrite; the growth morphology of the veins is antitaxial. According to the geometric analysis based on Lisle (2013) the volume loss of the analysed samples is between 41 % – 57 %. The changes in concentration of a wide list of elements and rock volume due to deformation can be computed by the mass balance method of Gresens (1967) and Grant (1986). The mass balance analysis was performed on the whole rock chemical analysis of samples from the shear zone and from the wall rock. Assuming immobile Ti, the shear zone is enriched in Ca, Mn, Ba and S. The volume change of the shear zone is –5 %, while the mass change is +9 %. Despite of the positive mass change, the system lost some volume without any visible evidence, like pressure solution seams. Micro CT analyses were carried out to quantify the density difference between the shear zone and the wall rock. Based on the CT data the average density of the rock bridges in the shear zones are higher than there in the undeformed wall rock. Accordingly the rock bridges between the veins went through density increase. All three approaches suggest that the studied tension gashes developed due to compaction during the development of the shear zone. This process coincided with a significant density increase and a volume loss of 5 %.

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Fracture network characterization using 1D and 2D data of the Mórágy Granite body, Southern Hungary

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A disposal system for low- and medium-level nuclear waste in Hungary is being constructed inside the fractured rock body of the Lower Carboniferous Mórágy Granite. Previous studies proved that the granitoid massif is rather heterogeneous in terms of lithological composition, brittle structure and hydrodynamic behaviour. A significant part of the body consists of monzogranite, while other portions are more mafic in composition and are monzonites. As a result of at least three significant brittle deformation events, the area is at present crosscut by wide shear zones that separate intensively fractured zones and poorly deformed domains among them. Due to late mineralization processes, some of these fractured zones are totally sealed and cannot conduct fluids, while others are excellent migration pathways. The spatial distribution of these two types nevertheless does not show any systematics. Hydrodynamic behaviour clearly reflects this heterogeneous picture; in some places, hydraulic jumps as great as 25 m at compartment boundaries can be detected.

In this study, the fracture network of the Mórágy Granite body is evaluated from a geometric aspect using datasets measured at a wide range of scales. 2D digitized images of a hand specimen, one large (20 × 60 m) and 12 smaller subvertical wall rocks (outcrops) and 120 images from tunnel faces representing the ground level of the underground repository site were analysed. Moreover, 1D data from 13 wells that all penetrate the granitoid massif were studied. Based on measured geometric data (spatial position, length, orientation, and aperture) fracture networks are simulated to study connectivity relations and for computing the fractured porosity and permeability at different scales. The results prove the scale-invariant geometry of the fracture system. Geostatistical calculations indicate that measurable fracture geometry parameters behave as regionalized variables and so can be extended spatially. Estimated localities of connected subsystems fit very well with fault zones mapped previously. Moreover, the spatial position of regimes of different hydrodynamic behaviours can be explained by connectivity relations both regionally and within wells.

Evolution and diversity of REE minerals dung Earth history: a consequence of tectonic and biosphere development

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Rare-earth elements (REE; La to Lu and Y) and their minerals belong to the most useful tracers in geochemistry, petrology and geochronology, mapping principal geological processes during Earth evolution. The REE minerals are characteristic constituents of Earth lithosphere, they occur as scattered accessory minerals to large deposit accumulations mainly in continental crust, especially in uncommon lithologies, such as nepheline syenites, rare-element granitic pegmatites, some skarns, and also in oxidation zone assemblages. Recently, 305 valid mineral species with REE as essential elements have been described; they occupy 5.6 % of all known minerals (~ 5450 species). Because of relatively low REE concentration in common rocks and their relatively low to moderate geochemical mobility, specific geological processes (such a volatile-rich magmatic to hydrothermal fractionation and metamorphic processes) led to concentrations sufficient for their saturation and precipitation as essential REE minerals. Consequently, first REE minerals originated at ca. 0.6–0.8 Ma after accretion of primitive Earth.

Application of the mineral evolution approach (e.g., Hazen et al. 2008, Grew and Hazen 2014, Grew et al. 2016) enables to recognize 5 basic stages of mineral evolution and diversification of REE species during Earth history:

(1) Hadean (4.56 to 4.0 Ga) stage with early, primitive differentiated lithosphere, extensive volcanism and hydrosphere evolution, probably without known essential REE minerals (possible presence of monazite and xenotime?); higher concentrations of REE were included in some accessory minerals (mainly apatite, zircon, garnet).

(2) Eoarchean to Mesoarchean (4.0 to 3.1 Ga) stage with mildly differentiated lithosphere and increased lithological contrast; first essential REE minerals were documented by U–Th–Pb dating (3.6–3.4 Ga): monazite-(Ce) and xenotime-(Y).

(3) Mesoarchean to Paleoproterozoic (3.1 to 1.8 Ga) stage with early plate-tectonic cycles in lithosphere, connected with first production of REE-rich rocks (rare-element pegmatites and nepheline syenites, 3.0–2.5 Ga); rise of cyanobacteria and other organisms, which led to the Great oxidation event (2.4–2.2 Ga); origin of new and complex REE minerals (up to 50–70 species?).

(4) Paleoproterozoic to Neoproterozoic (1.8 to 0.54 Ga) stage with advanced lithosphere, contrasting lithology and increasing interactions with oxygen-bearing atmosphere and organisms, producing new combinations of REE minerals (e.g., REE carbonates, phosphates); up to ~150 REE mineral species.

(5) Phanerozoic (0.54 Ga to present) stage with complex lithosphere, strong interactions with oxygen-rich atmosphere and expanding biosphere; main increasing of REE mineral diversity (up to > 300 known species), including typical high-oxidation and low-temperature minerals precipitating on the Earth surface (e.g., hydrous REE sulphates and oxalates).

Within REE minerals, Ce and Y species are the oldest; they formed from Paleoarchean era, whereas essential minerals of La appeared from Mesoarchean, Nd and Yb from Proterozoic, Sm and Gd only from Phanerozoic era. The increasing number and complexity of mineral species (including REE phases) show their gradual but episodic origin and diversification in irregular and relatively short steps. Production of new REE mineral species is proportional with increasing of other mineral diversity, due to diversification of magmatic activity and metamorphic processes during the development of plate tectonic and supercontinent cycles as well as exogenous and biogenic evolution during Earth`s history. The REE mineral diversity is driven especially by fluorine-rich alkaline magmatism connected with intracontinental rifting, production of rare-element pegmatites, and by exogenous oxidation and water-rich sedimentary processes, closely connected with increasing of geochemical activity and evolution of organisms.

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Magnetic fabrics of the Altenberg–Teplice caldera rhyolite ignimbrites recoding pyroclastic density current flow directions and primary welding

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The Altenberg–Teplice caldera is a Late Carboniferous volcano-plutonic complex in the northeastern Krušné hory/Erzgebirge batholith of the Saxothuringian unit (Bohemian Massif) at the Czech/German border. The complex is a representative of post-Variscan orogenic magmatism. Volcanic deposits occur in two main intracaldera units at the present-day erosional level. The relatively older Schönfeld volcano-sedimentary unit is located in the north-central portion of the caldera, whereas the younger and voluminous Teplice rhyolite occupy the eastern third of the caldera. The published biostratigraphic and radiometric dating of all the caldera magmatic units are not well constrained, however roughly indicate a span between 320–312 Ma. The Teplice rhyolite consists of fall tuffs, ignimbrites and lavas, locally intercalated with coal-bearing sediments. The eruptive sequence was divided into five volcanic phases characterized by reversed chemical zoning, of which only the fourth and fifth phases are exposed at the surface. This contribution focuses on two youngest exposed rhyolite types: Western margin (4th phase) and Pramenáč (5th phase). We aim to explore magnetic fabric as determined using the anisotropy of magnetic susceptibility (AMS) of the Teplice rhyolite in order to infer the intracaldera eruption dynamics, ignimbrite flow directions and degree of welding and rheomorphism. The macroscopic foliation of the Western margin type defined by shape preferred ordination of glass shards and fiamme dips shallowly to the east-south-east. By contrast, Pramenáč type shows no macroscopic fabrics. In total, we have collected 81 specimens of the Western margin type from 5 stations, and 59 specimens of the Pramenáč type from 3 stations. The AMS signal of the former is dominated by paramagnetic ferrosilicates, whereas the latter is characterized by ferromagnetic behaviour (low-Ti titanomagnetite). Degree of anisotropy (*P*) is generally low in both ignimbrite types ranging between 1.01–1.02 (1–2 % of anisotropy). However, both ignimbrite types significantly differ in the shape parameter (*T*) and grouping of principal susceptibility axes of individual specimens (k_1 - maximum, k_2 - intermediate, k_3 - minimum). The Western margin type has dominantly oblate shape of AMS ellipsoids and is characterized by girdle pattern of k_1 and k_2 centred around a cluster of k_3. In addition, the magnetic foliation (pole to k_3) corresponds well to macroscopic fiamme foliation. The Pramenáč type, on the other hand, shows neutral shape of AMS ellipsoids and well clustered all principal susceptibility axes around their mean value. We interpret the magnetic fabrics of the Western margin type as reflecting primary sedimentary fabrics indicating pyroclastic density current flow directions. In addition, the presence of flattened fiamme indicate a low degree of primary welding. By contrast, the Pramenáč type shows typical feature of initial ductile deformation imposed on primary sedimentary fabric, which marks increasing degree of welding compaction or even rheomorphic remelting of the ignimbrite. It remains unclear, whether such deformation obscures the original flow fabrics. Our further investigation will include detailed magnetic mineralogy analyses (*i.e.* hysteresis curves) and anisotropy of magnetic remanence (AMR), as well as extensive sampling of the Pramenáč type and other younger ignimbrite types of the 5th volcanic phase.

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View of the thrust structures development in the easternmost part of Ostrava Karviná Coalfield

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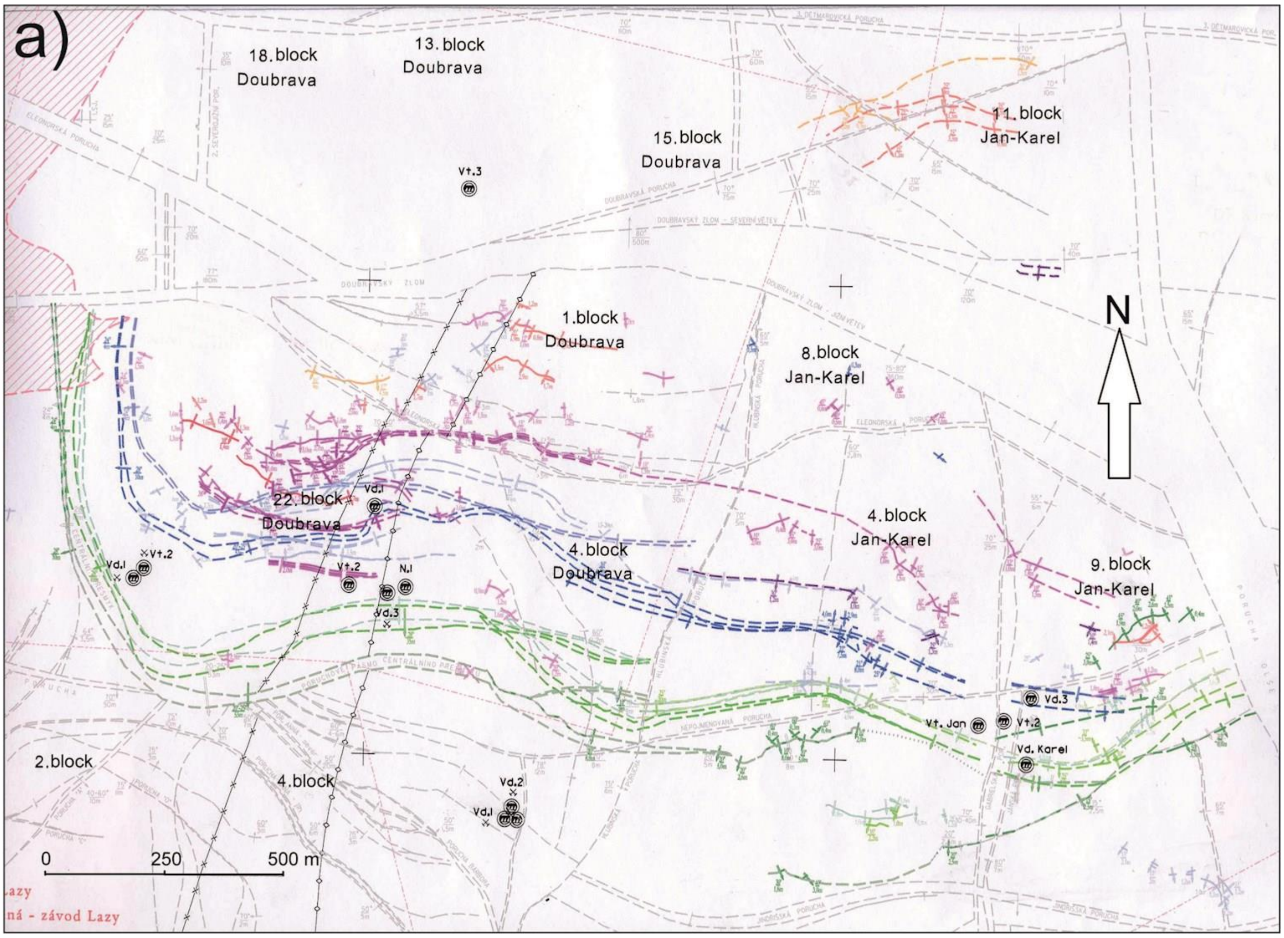
Ostrava Karviná Coalfield presents the Czech part of Upper Silesian Coal basin (USCB), which is the part of East-European Variscan orogeny. Czech part takes only one fifth of the basin, but due to the rich variety of the geological properties, it produces many themes for the studies of the geological structures. From this point of view, it is important that the coal basin is exploited yet. That is why; we can get new, very often unexpected findings, by mine advancing.

It is evident the division of the Czech part of USCB into western part with the high degree of folding and eastern part with subhorizontal bedding (Dopita et al. 1997). Similarly, we can observe the decrease of the deformation intensity eastward. But even in the easternmost part of Upper Silesian block, which is characterized by normal faults and brittle tectonics (Kumpera 1980), the compressional structures and flat folds are presented (Grygar et al. 1989, Ptáček 1999, Waclawik 2009, Grygar – Waclawik 2011).

As the structural pattern is very important for the mining design and planning, the high attention is paid to it since start of mining. The structural pattern is well known in general now, nevertheless many times we find out during mining development a new unexpected geological information, which we must solve operatively. The prediction of the faults course is not working. Similar, it was working in the case of thrusts systems in Upper Silesian block. Two systems of thrust structures were determined there, Central thrust, examined in Doubrava mine and Eastern thrust, described in detail in mines Darkov, ČSM and 9. květen. The both systems are considered originally make up a whole (Ptáček 1999), but following exploration during mining development shoved, that they are two independent systems (Waclawik 2009, Grygar – Waclawik 2011). Space orientation of thrust structures proves univocally that they are older than main normal faults system, which are corresponded with Variscan directions, approximately NNE–SSW and WNW–ESE.

The direction of Central thrust changes from the West to the East. Originally N–S direction rotate to W–E direction. In the Fig. 1a), there are depicted its traces in the seams levels in Doubrava and Jan-Karel mines. Eastern thrust respects the direction similarly NE–SW, but it changes locally too. Its traces in the seams are evident from the Fig. 1b).

The nature of Eastern thrust (see Fig. 1b) approximates to the thrust structures in apical zone of orogenic front. It consists of the flat thrusts combined with the interlayer slip. But the faults of Central thrust system described in Doubrava mine are mostly of the same character. The change of motion amplitude is the important feature for the both thrust systems. While the amplitude of the Central thrust decrease to the East, the amplitude of the Eastern thrust decrease to the SW. That fact was the main argument for dividing overthrusts into two separately systems. But for decisive factor, we consider the change of maximal horizontal stresses, measured in the regions of both thrust systems, In the region of Central thrust prevails N–S direction, while in the region of Eastern thrust system NW–SE direction. The different mobility of constituent elements of Variscan rock mass is considered for decisive source of it. It develops, due to locally increasing of press, to breaking up the originally consistent rock mass into the individual blocks. The block mobility differentiation caused the dextral strike slip, which is clearly documented in the Western and central part of Ostrava Karviná Coalfield. Horizontal moving component is often more than 100 meters. Similarly, the function of dextral strike slip of the blocks is visible in the Fig. 1a). The traces of the Central thrust in the seam No. 24 (yellow color) are shifted eastward in the North block (block No. 11, Jan Karel) compared to South block (block No. 1, Doubrava). This is, after all, the evidence of the relative age of the overthrusts and normal fault systems. The overthrust systems originated probably in the early phase of Variscan orogenic processes and they were gradually deformed by following movement including the dextral rotation of the blocks.



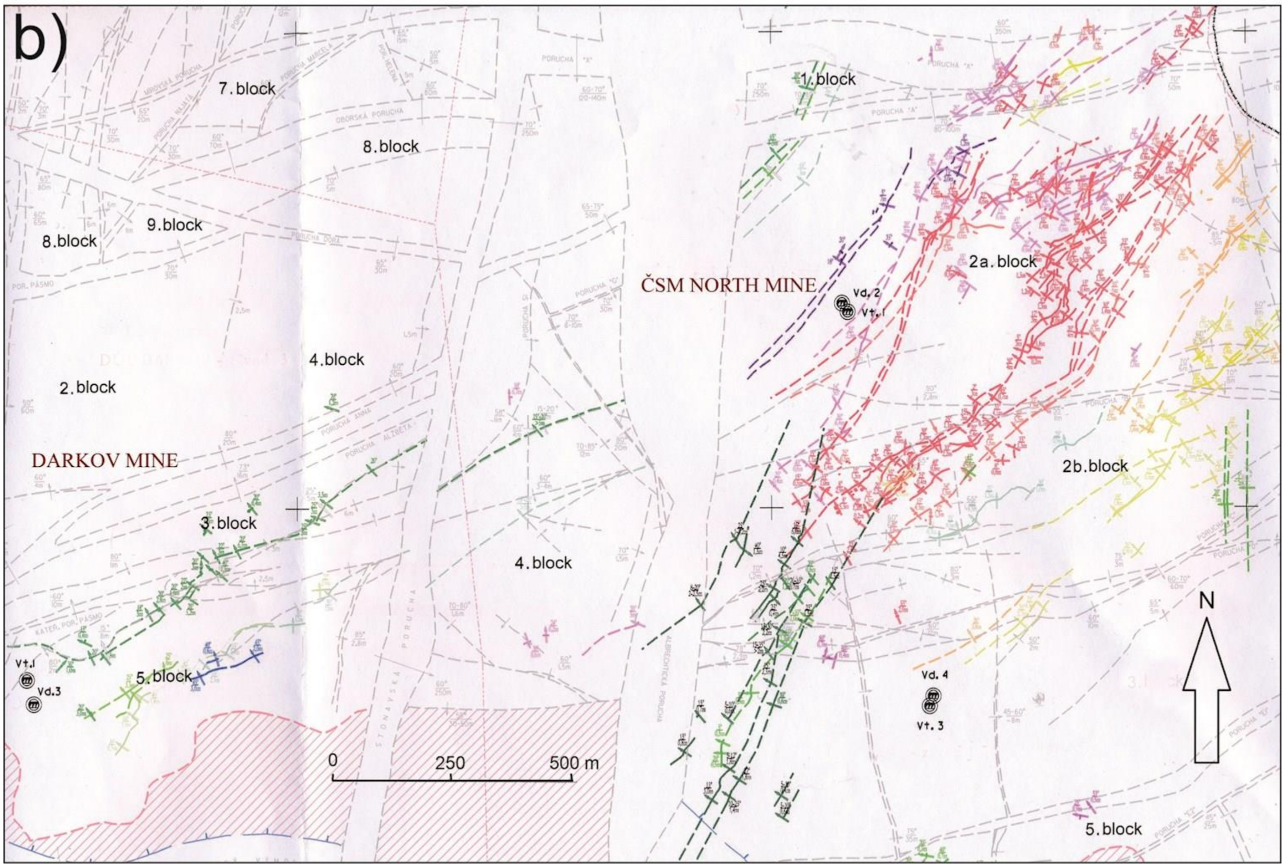


Fig. 1. Lines of a) Central thrust and b) Eastern thrust in the seams levels No. 23 to 40 (the fault structures in level of seam No. 40 are depicted in grey).

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New data on the age of magmatic rocks in the Khasagt Mts (Zavkhan terrane, Western Mongolia)

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We present the results of dating of different magmatic rocks in the western part of the Khasagt Mountains (Western Mongolia). The study area represents SW margin of the Zavkhan (Dzabkan) terrane, within the Central Asian Orogenic Belt (CAOB). U–Pb isotope dating was made by the PIG-PIB Ion Microprobe Labolatory. The first group of the samples came from intrusions bodies in Proterozoic volcano-sedimentary succesion of allochtonous unit known as the Urgamal Zone. The granitoid rocks of the Dund orthocomplex were dated for period from 816 ± 4 Ma to 775 ± 5 Ma (most frequently about 800 Ma) and associated ryolites were dated at 784 ± 7 Ma (Wójcik et al. 2017). These dates are similar to the results published by Bold et al. (2016).

The second group of the samples came from granitoid pluton (Numrug complex) and accompanying bimodal (ryolites and basalts) volcanic rocks which intruded the Neoproterozoic – Lower Cambrian succesion of the Tsagaan Oloom Basin (autochthonous unit known as the Khasagt Zone). Previously described as Lower Devonian (Enkhbaar et al. 2005), according to our data results turned to be Permian ages. These intrusions took place over the period from 267.4 ± 3.8 Ma (ryolites) to 275.2 ± 5.9 Ma (granitoids). Received ages of rocks correspond to the 286.1 ± 5 Ma (Kilian et al. 2016) ages of the Thonkil complex granitoid pluton situated on the east from Numrug complex.

However Tonnian ages of igneous rocks from Dund orthocomplex were expected, the Permian ages of the Numrug complex granitoids and associated volcanic rocks are surprising. All the received dates allow for the revision of the current concepts of magmatic succesion on SW margin of the Zavkhan terrane.

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Melt driven weakening and exhumation of the High Himalayan Crystalline (HHC) in Zanskar

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The exhumation of the orogenic infrastructure, represented by the High Himalayan Crystalline Sequence (HHCS) of the Himalayan orogen, is considered to be stimulated largely by melt-assisted deformation in the orogenic lower crust and gravity driven pressure gradients. However, major questions regarding the evolution of the HHCS relating to the number, extent, timing, and mechanism of the melting events and their connection to major geodynamic processes remain.

The Zanskar region at the northwestern part of the Himalayan mountain range exposes an excellent area, where the relationships between deformation and melting can be studied in detail in the framework of an actively building mountain range. The Zanskar Shear Zone (ZSZ), an extension of the South Tibetan Detachment Zone (STDZ), juxtaposes low-grade or unmetamorphosed sediments of the Tethyan realm against the high-grade orogenic infrastructure, represented by the migmatitic HHCS. The contact between these two units is formed by a ~ 1 km thick Zanskar normal shear zone, trending northwest to southeast and marked by a dense crosscutting network of leucogranite sheets and plutons in dome like culminations along and below the shear zone interface. The HHCS below the ZSZ is represented by two principal lithologies that are locally migmatized, a meta-sedimentary sequence and granitic orthogneiss. In structurally low levels, the orthogneiss reveals augen structure and minor solid-state deformation of the original metagranites within low-strain domains. Higher up in the sequence, the orthogneiss contains abundant leucosomes.

The meta-sediments bear witness to an old episode of partial melting as evidenced by the occurrence of micro-granite (Qtz + Pl + Ksp + Bt) inclusions in peritectic garnet at contact with orthogneiss. Progressive migmatization (presumably of Oligocene–Miocene age) in both the metasediment and the metagranite is associated with intrusion of leucogranites along the original subvertical S_1 northeast-southwest foliation, perpendicular to the Zanskar shear zone (ZSZ). Towards the ZSZ, this S_1 fabric is progressively reworked by an axial planar cleavage, which is parallel to the ZSZ and is marked by fold axes plunging shallowly to the northeast. This cleavage is again coated by leucosomes, garnet bearing leucogranite dykes or diffuse anatectic zones that divide lithons of chevron like crenulations of the S_1 schlieren migmatites derived from the granitic orthogneisses.In contrast, the transposition of the S_1 leucosome bearing layering in the metasediments by the ZSZ parallel fold axial planar cleavage is associated with emplacement of cross-cutting leucogranite and pegmatite dykes in arrays parallel and oblique to the ZSZ.

While the solid-state orthogneisses show weak recrystallization of K-feldspars by myrmekitization, recrystallization of plagioclase into polygonal mosaics and dynamic recrystallization of quartz within ribbons (+ Ky, Grt, Mnz, Zrc), the migmatized orthogneisses are marked by K-feldspar and quartz rich leucosomes surrounded by a fine-grained matrix of intergrown plagioclase and quartz with minor K-feldspar. The clear outcome of our structural mapping survey is that the vertical channeling of the leucocratic melts (presumably during the Miocene – Oligocene) did not occur exclusively along the crustal scale ZSZ, but along the vertical fabrics of the lithological units in the HHCS at a high angle to the ZSZ.

Synmagmatic leucogranites related to the southern part of the Třebíč pluton

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The Třebíč Pluton is a Variscan body, which has been intensively studied from the petrographical, geochemical and geochronological point of view. On the other hand, granitic dykes and bodies accompanying the durbachite intrusion remain poorly described.

Two types of granites were sampled and studied in detail: anatectic leucogranite derived from the host rocks during emplacement of the Třebíč Pluton and tourmaline granite dyke from the Výčapy quarry.

Anatectic leucogranite rims the contact between Třebíč Pluton and Moldanubicum at Jirkasův mlýn in the Jihlava River valley close to Vladislav. It represents the “in situ” melted wall rocks of intrusion. The rock is white, medium-grained. Modal composition includes plagioclase and quartz, K-feldspar is present only in small exsolutions in plagioclase grains, biotite is relatively rare and often chloritized. Apatite and zircon are accessoric. Plagioclase is zoned, central parts correspond to andesine ($An_{45–48}$), rims are oligoclases (An_{22}). Biotite, when preserved, has XFe = 0.48–0.5.

Tourmaline granite froms E–W trending, several kilometres long and tens of meters wide dyke in durbachite. Sample from the old quarry east of Výčapy is medium-, locally coarse-grained rock with irregularly distributed tourmaline columns up to 5 mm long. It is formed of K-feldspar, plagioclase, quartz, tourmaline, muscovite and biotite. Apatite, zircon, monazite and cassiterite are accessoric. K-feldspar is orthoclase with admixture of albite component ($Ab_{5–7}$). Plagioclase is relatively rare, represented by albite with a maximum content of anorthite component An_7. Chemical composition of the tourmaline indicates Al-rich schorl (XFe = 0.66–0.80; Al = 6.56–6.79 apfu). In the X site prevails Na (0.44–0.67 apfu). Clots of chlorite and muscovite mixtures, often accompanied by tourmaline, make nets indicating apparently pseudomorphs after an original biotite.

Both mentioned rock types are rich in silica (SiO_2 = 74.2–74.5 wt. %). According to P-Q classification of Debon and Le Fort (1983) they are granites, falling near to a boundary with the adamellite field. All analyses show peraluminous character (A/CNK = 1.11–1.29).

Zircons from three samples were dated in situ by laser ablation U-Pb method at the Institute of Geology of the Czech Academy of Sciences in Prague.

Clear or pale brown zircons from anatectic leucogranite (Jirkasův mlýn) were long prismatic or needle-shaped up 500 µm; prismatic grains 100–300 µm or their stubby fragments. They have well-developed oscillatory zoning in dark rims and also very often bright xenocrystic cores with features of alteration. Concordant analyses provide an age of 332 ± 3 Ma (2σ) interpreted as anatexis of magmatite caused by a durbachite intrusion heat. Cluster of ages with concordant age of 478 ± 5 Ma (2σ) detected in well-preserved oscillatory igneous zones reflects obviously an age of the source to the leucogranite magma.

Tourmaline leucogranite from Výčapy contains prismatic or long prismatic zircon grains up to 200 µm long that have dark oscillatory zones on the rims and slightly recrystallized bright cores in CL. Concordant analyses provide an age 330 ± 3 Ma (2σ) detected in well-preserved oscillatory igneous zones interpreted as an intrusive age.

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Record of metamorphic and metasomatic processes at the contact of felsic and mafic rocks in high-temperature conditions (Dunkelsteiner Wald granulite massif, Bohemian Massif)

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Dunkelsteiner Wald granulite massif is situated in the Gföhl unit of Lower Austria and is dominantly formed by felsic granulite, however it contains large number of smaller mafic to ultramafic bodies such as pyroxenites, peridotites, and eclogites. The contact of the felsic granulites with these bodies is sometimes accompanied by occurrence of mafic and intermediate granulites with specific mineralogical and textural characteristics.

Primary mineral assemblage of garnet pyroxenites and mafic granulites is similar and formed by clinopyroxene and garnet, some samples may contain kyanite and quartz as inclusions in garnet. Mafic granulites may moreover contain aggregates of Ca-rich plagioclase grains hosting grains or symplectites of spinel and/or sapphirine, which are interpreted as relics after kyanite. The garnet pyroxenites show rather limited extent of metamorphic overprint reflected by formation of ortopyroxene and plagioclase coexisting with dipsidic clinopyroxene. In the mafic granulites the degree of the overprint is much higher. The matrix re-equilibrated mineral assemblage is formed by garnet, clinopyroxene, plagioclase and orthopyroxene with minor amphibole, spinel and saphirine. Texture of mafic granulites is characterizated 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.

Clinopyroxene in both lithologies is jadeite- and CaTs-rich (up to 25 % of jadeite and 13 % of CaTs) with orthopyroxene lamellae and compositional zoning characterized by Al and Na decrease toward the rims. 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 in intermediate and mafic granulites and garnet pyroxenites drastically affected by diffusion resulting in considerable Ca-depletion associated with enrichmend in Mg and Fe. Primary garnet growth zoning in studied lithologies can be traced only by Cr-poor core.

The mineral assemblage of felsic granulites was formed by garnet, kyanite, quartz, plagioclase, K-feldspar and rutile. The primary mineral assemblage of the intermediate granulites preserved as relics was similar but additionally contained clinopyroxene. However the dominant mineral assemblage is characterized by occurrence of orthopyroxene in matrix and kyanite breakdown to mixture of corundum and clinozoisite surrounded by garnet corona.

P–T conditions of the metamorphic evolution of the selected lithologies were estimated by thermodynamical modelling. Primary mineral assemblage of mafic granulites and garnet pyroxenites was formed in eclogite facies under conditions of 25 kbars and 900°C, then these rocks were isothermally decompressed to 10 kbars corresponding to granulite facies. Metamorphic evolution of intermediate and felsic granulites is similar and characterized by decompression with temperature increase starting at the border of eclogite-granulite facies 13–16 kbars and 800°C to 6–11 kbars and 900–1000°C.

The whole rock geochemical characterization of the lithologies has shown clear chemical similarity of mafic granulites with garnet pyroxenites, but mafic granulites are considerably depleted by MgO, FeO and LREE and enriched by K_2O, SiO_2, Al_2O_3 and Na_2O. Similarly, there is an apparent affinity of intermediate granulites to 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.

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

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