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XXIII^rd Meeting of the Petrology Group of the Mineralogical Society of Poland

Subduction systems in the Sudetes and related areas

Abstracts and field trip guide

Stara Morawa, Poland, 20-23 October 2016

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Editor of the series:
Marek MICHALIK
Institute of Geological Sciences, Jagiellonian University
Oleandry 2a, 30-063 Kraków, Poland
marek.michalik@uj.edu.pl

Editors of Volume 45:
Krzysztof DUDEK, Jarosław MAJKA
AGH – University of Science and Technology
Faculty of Geology, Geophysics and Environmental Protection
Al. Mickiewicza 30, 30-059 Kraków, Poland
kadudek@agh.edu.pl, jmajka@agh.edu.pl

Language correction:
Christopher BARNES, Jarosław MAJKA, Iwona KLONOWSKA,
Krzysztof DUDEK, Katarzyna WALCZAK, Karolina KOŚMIŃSKA
AGH – University of Science and Technology,
Faculty of Geology, Geophysics and Environmental Protection
Al. Mickiewicza 30, 30-059 Kraków
Department of Earth Sciences, Uppsala University
Villavägen 16, 752-36 Uppsala, Sweden
cjbarnes063@gmail.com, jaroslaw.majka@geo.uu.se
iwona.klonowska@geo.uu.se, kadudek@agh.edu.pl
katarzyna.walczak@agh.edu.pl, k.m.kosminska@gmail.com

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Subduction systems in the Sudetes and related areas

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Stara Morawa, Poland, 20-23 October 2016

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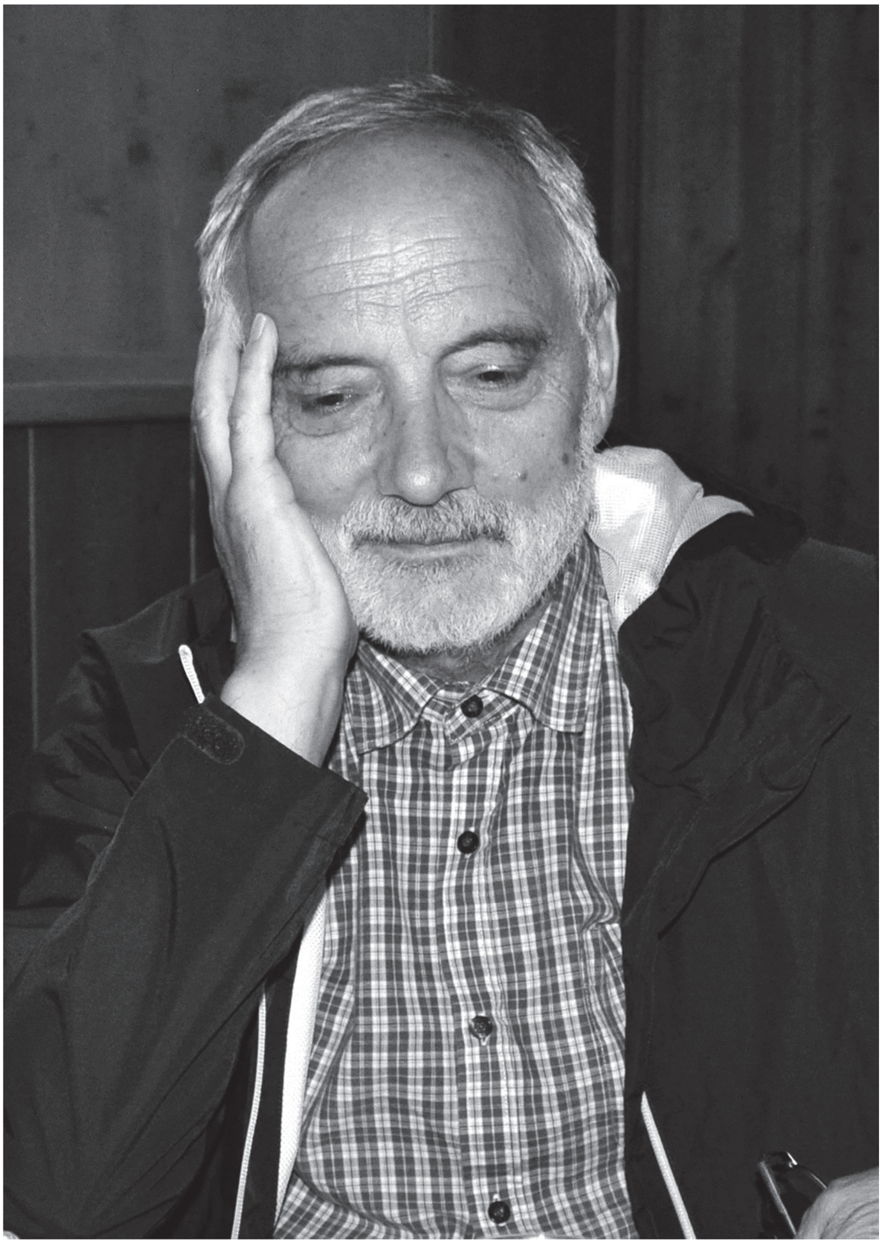
XXIIIrd Meeting of the Petrology Group of the Mineralogical Society of Poland

Dear Colleagues,

Welcome to the XXIII Session of the Petrology Group of the Mineralogical Society of Poland entitled "Subduction systems in the Sudetes and related areas". The conference is held in Stara Morawa on 20th – 24th of September 2016. This periodical conference is back to its source place, the Sudetes Mountains, where the first session took place more than thirty years ago. The XXIII Session is organized by a relatively young and dynamic team of researchers led by dr hab. inż. Jarosław Majka from the Uppsala University and AGH – UST Kraków. The conference is devoted to recent studies on the subduction systems in the Sudetes and related areas as well as ancient and current analogues. However, the regular open session of the meeting in addition to main conference topic covers, as always, various fields of mineralogical sciences, including mineralogy, petrology, geochemistry, environmental and related sciences. On the occasion of the conference, it is impossible not to mention Prof. Ryszard Kryza, the former president of the Mineralogical Society of Poland, who passed away late last year. He was always an active participant of the Mineralogical Society conferences and his world-class research aroused interest and admiration. This year's theme of the conference is so close to his scientific interests that I'm sure his spirit will be with us during the whole Session. Let the conference be scientifically successful and let all the participants take excellent impressions from Stara Morawa 2016.

Leszek Marynowski

President of the Mineralogical Society of Poland



RYSZARD KRYZA (1950 - 2015)

On 25th December 2015, Professor Ryszard Kryza passed away. He had been fighting severe illness for the last few years. His coworkers, friends and family all hoped that Ryszard's will to live, aided by modern medicine, would win. Suddenly and sadly, the opposite happened...

Professor Ryszard Kryza was a wonderful man and a fine geologist, an authority in many everyday affairs and in scientific problems. He kept commitments, met deadlines, kept his word, and always had time for other people, for students and co-workers. He managed to point out simple solutions to intricate problems and gave effective advice when faced with challenges. Ryszard Kryza was unusually diligent and never wasted a minute of time. Despite his great achievements in his professional career, he did not care much about honours. He was passionate about travelling, photography, music; he loved to be with people and together to explore new, exotic tastes of the world. During the fight for democratic change in Poland, in the 1980s, as an active member of the "Solidarity" movement he was oppressed by the communist authorities, e.g. by the repeated refusal to grant him a passport. Ryszard Kryza was deeply involved in various aspects of the organization of academic science and teaching. Thanks to him, several tens of students and young aspiring geologists were able to initiate and develop the international scientific contacts which are so important for present-day academic careers. For his coworkers and university colleagues, Ryszard Kryza created possibilities for free scientific and organizational development. The results of his work place Ryszard Kryza among the most deserving and outstanding scientists of the University of Wrocław.

Professor Ryszard Kryza was a great authority in Earth Sciences, of unusually broad scientific horizons. In his studies he managed to join the seemingly disparate elements of various branches of Earth Sciences, and to find solutions to problems of both basic and applied science. He was among the very top group of most-cited Polish geologists. He was the author and co-author of over 400 scientific publications. He was a fine mineralogist, petrologist and geologist, deeply involved in the study of the European Variscides and the Sudetes. His work on the petrology and geochronology of the crystalline rock complexes of the Sudetes, including studies on metabasites, ophiolites and high-pressure metamorphic rocks, were, in many cases, pioneering, and greatly helped our understanding of the evolution of the eastern part of the European Variscides. In recent years he was also a co-discoverer of new minerals in meteorites. He contributed significantly to our knowledge of the stone materials used in monuments and buildings, and their deterioration, in Lower Silesia, in Wrocław, Vilnius and St. Petersburg. He was the leader and principal investigator in several research projects carried out in Poland and abroad. He organized geological and mineralogical congresses, conferences and meetings. For twenty years, Ryszard Kryza was the head of the Department of Mineralogy and Petrology at the University of Wrocław. He successfully organized laboratories at the University. He was the leader of scientific collaborations between Wrocław University and several academic and research institutions abroad. He was involved in teaching at the University as a lecturer as well as the promoter and coordinator of new teaching programmes and the leader of specializations in mineralogy and petrology.

Professor Ryszard Kryza was an active member of several professional organizations, societies and committees in mineralogy, petrology and geology. He was the President of the Mineralogical Society of Poland (2009-2012), a member of the Committee of Mineralogical Sciences of the Polish Academy of Science, and in recent years a member of the Committee of Geological Sciences of the Polish Academy of Science and a member of the Polish Central Committee for Degrees and Titles. He was a member of the editorial boards of scientific journals and prepared a great number of reviews of papers submitted to the highest ranked scientific journals. Ryszard Kryza received many awards and decorations, including the Ignacy Domeyko Award of the Polish Academy of Science, the individual award of the Ministry of National Education, the Gold Cross of Merit, and several tens of Awards of the Rector of the University of Wrocław for achievements in science and didactics. In autumn 2015, he was awarded the Gold Medal of the University of Wrocław.

But, sadly, he was not strong enough to accept this last honour personally.

Marek Awdankiewicz

XXIIIrd Meeting of the Petrology Group of the Mineralogical Society of Poland

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Invited lectures

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Metasomatism During High-Pressure Metamorphism: Eclogites and Blueschist-Facies Rocks

Reiner KLEMD[1]

[1]*GeoZenrum Nordbayern, Universität Erlangen-Nürnberg, Schloßgarten 5a, 91054 Erlangen, Germany; e-mail: klemd@geol.uni-erlangen.de*

Arc magmas, generated within subduction zone settings, exhibit a characteristic geochemical signature with elevated concentrations of relatively fluid-mobile elements such as the large-ion lithophile elements (LILE) and the light rare earth elements (LREE), and low concentrations of the high field strength elements (HFSE) and the heavy rare earth elements (HREE). There is general agreement among researchers that this characteristic is caused by additions of 'fluids' and or/melts derived from the subducted slab, thereby fluxing the melting in the overlying metasomatized mantle wedge to generate arc magmas. These fluids or melts are considered to have been liberated during high-pressure (HP) to ultrahigh-pressure (UHP) metamorphism in the (variably hydrothermally altered) subducted oceanic lithosphere. Neglecting the expulsion of large volumes of pore water during initial subduction, solute-poor aqueous fluids derived by prograde HP metamorphic devolatilization reactions are usually held responsible for the trace element transfer between the slab and mantle wedge, with both of these environments showing significant metasomatism. At deeper levels in the subduction zones, at UHP conditions, dense solute-rich transitional fluids (intermediate between hydrous silicate melts and aqueous fluids) or hydrous silicate melts are thought to become more important agents of element mobilization and transport. An understanding of the metasomatic processes leading to the mobilization and redistribution of major and trace elements within subduction zone rocks is crucial for (quantitatively) evaluating bulk compositional changes which occurred under HP and UHP conditions. HP and UHP rocks, representing parts of ancient subducted slabs, are obvious targets for the study of P-T conditions as well as composition and type of slab-derived fluids responsible for metasomatism in subduction zone environments as these rocks are the only direct witnesses of such processes. This lecture focuses mainly on characterizing the composition of the fluid phase liberated during prograde-dehydration reactions and its impact on rock compositional changes (metasomatism) during fluid-rock interaction. Furthermore, it reports on recent studies of compositional (metasomatic) changes in various HP to UHP meta-sedimentary, meta-igneous, and meta-ultramafic rock types derived from former subducted oceanic lithosphere and continental crust.

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Diamond and zircon – witnesses of deep subduction of continental crust to mantle depths

Jana KOTKOVÁ[1,2]

[1]*Czech Geological Survey, Klárov 3, 118 21 Prague 1, Czech Republic; jana.kotkova@geology.cz*
[2]*Department of Geosciences, Masaryk University, Kotlářská 2, 611 37 Brno*

Introduction

Presence of coesite, and diamond, phases stable above 3 and 4, in rocks of continental crustal origin provides evidence for deep subduction of continental slab into the mantle in collisional orogens. Increasing number of finds of especially diamond demonstrates that this process operated during formation of terranes of variable age worldwide, including the Dabie-Sulu orogen, Alps, Himalaya, Scandinavian Caledonides, as well as the European Variscan belt. Joint study of tiny diamonds, when well preserved, and zircon, containing diamond inclusions, using micro-nano-techniques is an unparalleled way to get insight into the large-scale, subduction-related processes and their timing.

Diamonds

Micro-diamonds in UHP metamorphic rocks are usually enclosed in major phases, such as garnet and kyanite, and in accessory phases, e.g. zircon. As shown by experimental works, diamond morphology and surface, which can be imaged and analyzed using SEM and AFM, reflects physical conditions of diamond formation i.e. P, T, a_{H2O}, and presence of impurities. Micro-Raman along with FIB-TEM allows characterization of associated phases, diamond structure and composition of inclusions in diamonds when present, which altogether provide constraints on diamond-forming media. And finally, carbon isotopic composition (SIMS) characterizes the carbon source. For most of the methods used, however, except for TEM where it can be an advantage, presence of graphite coatings on diamonds is fatal.

Zircon

Zircons in polymetamorphic rocks are commonly zoned, which is revealed by CL imaging. Use of SIMS facilitates characterization of chemical and isotopic composition of individual domains, and micro-Raman is useful for documenting enclosed phases, e.g. diamond, in these domains. As zircon is resistant to diffusion and isotopic exchange, it is an ideal tool to establish link between the age, P-T conditions of its formation, and isotopic composition of the media from which it crystallized. These are reflected by concentrations and isotope ratios of trace elements with relatively low diffusivities, such as O, Pb, rare earth elements (REE), U, Th, Ti and Hf.

North Bohemian Rhapsody

Microdiamonds in UHP rocks from northern Bohemian Massif in the Variscan belt in Europe (Kotková et al. 2011; Fig. 1) represent unique material to study deep subduction processes, their timing and potential crust-mantle interactions. This is because they are well-preserved, and they occur both in major (garnet, kyanite), and accessory (zircon) phases in two contrasting rock compositions, acid and intermediate. Last but not least, diamond-bearing rocks are associated with mafic and ultramafic rocks which formed under UHP-UHT conditions comparable to those they experienced, which supports the deep crustal subduction scenario (Haifler, Kotková 2016; Medaris et al. 2016; Kotková, Janák 2016; Fig. 2a).

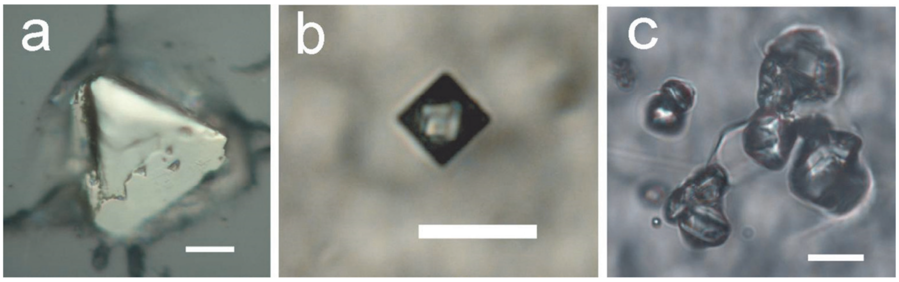

Fig. 1. Octahedral diamonds within garnet (a) and kyanite (b) in acid UHP gneisses, and a cluster of cuboids within garnet in UHP garnet-clinopyroxene rock(c) from northern Bohemia. Scale bar corresponds to 10 μm. Adapted from Kotková et al. (2011).

SEM imaging revealed that acid UHP gneiss, composed of garnet, kyanite, feldspar and quartz, contains individual diamonds with perfect octahedral shape and smooth surface. In contrast, diamonds in the intermediate UHP rock (garnet-clinopyroxene-feldspar-quartz) are cuboids with imperfect shape and rough surface. In both rock types, diamonds can be associated with quartz, apatite, rutile and Ca-Mg carbonate. FIB-TEM study showed that octahedral diamonds are single crystals, whereas cuboids are commonly polycrystalline. Importantly, both diamond types are practically devoid of any inclusions, which contrasts with skeletal inclusion-rich microdiamonds described in other world locations. Nevertheless, relics of amorphous material have been preserved in several voids close to diamond-host boundary (diamond octahedra) and in interstitial spaces and triangular gaps at diamond-host boundary (cuboids). This material is considered to be a residual, quenched melt after diamond formation. It contains a large range of elements, including Ca, K, Al, Cl, Fe, Zn and S, in both rock compositions. Rare pointed-bottom negative trigons observed on (111) faces of diamond octahedra (AFM) suggest dissolution of diamonds in water-rich fluids: similar features have been observed in HP-HT experiments (e.g. Zhihai et al. 2015). The data suggest that microdiamonds formed from dense C-O-H fluids/melts containing carbonate, silicate, saline, sulphate and phosphate component. In view of no difference in composition of the residual melt, the contrasting diamond morphology most probably reflects a different degree of supersaturation of the medium and different growth rate. SIMS-determined $\delta^{13}C$ values of diamond ranging between -22 and -33‰ correspond to those typical of organic carbon, thus providing an independent proof of crustal source of diamond-forming media.

The diamond-bearing zircon domain (Fig. 3b, c) shows relic oscillatory zoning, preserves steep HREE patterns, contains 110-190 ppm Ti and has uniform Th/U ratios ~ 0.1-0.2. This allows constraining peak UHP-UHT conditions of c. 1100°C and 4.5 GPa (Fig. 3a), and – along with thermodynamic modelling – suggests that the host zircon crystallized at UHP-UHT conditions from the low-volume water-undersaturated partial melt. Homogeneous oxygen isotope composition of zircon ranging between 7.8‰ and

9.6‰ reflects a source containing upper crustal material and homogenization at UHP-UHT conditions. In contrast, the non-equiliberated ƐHf values as well as a large range of the Hf-depleted mantle model ages possibly reflect presence of a heterogeneous population of old zircon, characteristic of metasediments. The three zircon domains, i.e. cores, diamond-bearing mantles and rims, yield U-Pb SIMS concordia ages of 340.9±1.5, 340.3±1.5 and 341.2±3.4 Ma, respectively. Trace element contents allow linking of the zircon mantle and rim ages to the previously reconstructed P-T path, and the error limits constrain the exhumation of the rocks from depth of ~ 140 Ma (UHP) to ~ 80 km (HP) to a minimum rate of 1.5 cm/yr (Kotková et al. 2016).

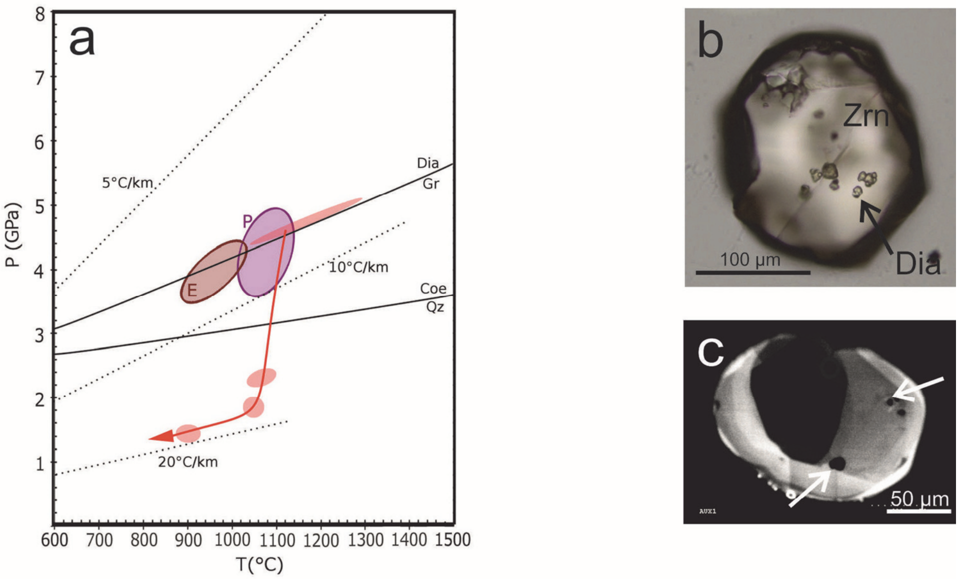

Fig. 2. (a) P-T path of the UHP rocks from North Bohemia; P and E mark the peak P-T conditions determined for the associated peridotites and eclogites. (b) Diamonds enclosed in zircon. (c) CL image showing the dark core, diamond-bearing mantle and CL-bright rim of zircon from the North Bohemian UHP garnet-clinopyroxene rock. Diamond indicated by arrows. Adapted from Kotková et al. (2016) and Haifler, Kotková (2016).

Conclusions

Diamond and zircon characteristics provide consistent and complementary evidence for water-undersaturated melting of a continental crustal slab at UHP-UHT conditions during its deep subduction into the mantle. Composition of the diamond-forming fluid/melt, carbon isotope composition of diamond, oxygen isotope composition and ƐHf values of zircon all reflect crustal, possibly meta-sedimentary source of the media from which they formed. The data did not reveal any important chemical interaction between the deeply subducted crust and the mantle, despite the present close association with ultramafic rocks formed at similar UHP-UHT conditions. In addition to elucidation of the processes during deep crustal subduction, the study allowed calculation of a high exhumation rate for the diamond-bearing rocks, which is consistent with the steep P-T path as well as preservation of the diamond and zircon from the UHP-UHT stage. The northern Bohemian diamond-bearing rocks formed during the Carboniferous deep subduction event, overlapping SIMS U-Pb ages implying that the sequence of events was faster than the technique can resolve.

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How the Avalonian-Cadomian basement of Gondwanan Europe was formed?

Ulf LINNEMANN[1]

[1]*Senckenberg Naturhistorische Sammlungen Dresden, Museum für Mineralogie und Geologie, Königsbrücker Landstraße 159, Dresden, D-01109, Germany; ulf.linnemann@senckenberg.de*

LA-ICP-MS U-Pb ages and Hf isotopes of detrital zircon became in the last years a powerful tool for the reconstruction of orogenies. We applied the detrital zircon record of Neoproterozoic glaciomarine deposits and adjoining sedimentary and igneous rocks of Avalonia and Cadomia for the reconstruction of timing, of crustal growth, and tectonothermal episodes. In the Cadomian orogen of the NE Bohemian Massif a ca. 565 Ma old glacial event is detected. Glaciomarine metasediments occur in the Weesenstein, Clanzschwitz, and Rödern groups of the Elbe zone and the North Saxon Antiform of the Saxo-Thuringian zone (Ediacaran, western peri-Gondwana, Central European Variscides) and are characterized by glaciomarine sedimentary features like dropstones, flat iron shaped pebbles, facetted pebbles, and zircon grains affected by ice abrasion. The maximum age of the glaciomarine deposits within a Cadomian back-arc basin is provided by U-Pb ages of youngest detrital zircon populations showing an age of 562-565 Ma. Upper time mark is given by ca. 538-540 Ma aged plutons intruded into the previously deformed Ediacaran metasedimentary rocks. Correlation with glaciomarine deposits in the Anti-Atlas (Bou Azzer) suggests a depositional age within the age bracket of 540-565 Ma, likely closer to ca. 565 Ma. Described glaciomarine tillites of Cadomia are definitely younger than the ca. 582 Ma old Gaskiers glaciation in Newfoundland (Gaskiers) and SE New England (Squantum). We propose for the new Ediacaran glacial event the term *Cadomian glaciation* because of its occurrence within the Cadomian orogen and the existence of equivalent strata in other parts of Cadomia, i.e. in the Iberian and in the Armorican massifs. To characterize the palaeogeographical position of Ediacaran glaciomarine deposits in western peri-Gondwana, we developed the idea of zircon provinces based on U-Pb ages of detrital zircon for Cadomia, Avalonia, and adjoining cratons like West Africa, Baltica, and Amazonia. According to the constraints given by U-Pb ages of zircon provinces, the ca. 565 Ma old glacial deposits of Cadomia in Bohemia show a strong palaeogeographical affinity to the margin of the West African craton, while glacial deposits of Avalonia (Gaskiers, Squantum) reflect a provenance to peri-Baltica. An Amazonian provenance for Avalonia can be completely ruled out. Glaciomarine deposits with an age of about 565 Ma occur in Cadomia and within the Ediacaran sedimentary cover of the West African (Anti-Atlas) and Arabian mainlands. Avalonian glacial deposits aged at ca. 582 Ma occur in the peri-Baltic realm and could correlate with the Moelv tillite in Baltica. Glacial and pre-glacial deposits of Cadomia act also as a perfect archive concerning timing and crustal growth of the Cadomian orogen and its hinterland. Zircon U-Pb ages of the Weesenstein, Clanzschwitz, and Rödern groups (Elbe zone, North Saxon antiform, Saxo-Thuringian Zone) identify the West African craton as the hinterland for the Cadomian Orogen as demonstrated by zircon populations dated at 1.8-2.2, 2.5-2.7, 3.0-3.2, and 3.4-3.5 Ga. The dominant zircon population is derived from a Cadomian magmatic arc in a time slice of ca. 565-750 Ma with a distinct maximum at ca. 570-580 Ma. The magmatic activity of the Cadomian arc stopped at ca. 565 Ma. Granitoid plutonism at 537 to 540 Ma documents the final pulse of the Cadomian orogeny. Hf isotope compositions, calculated εHf values and T_{DM} model ages for detrital and magmatic zircon show that during the ca. 185 Ma long Cadomian magmatic arc activity juvenile arc magmas were contaminated by recycling of Eburnian and Archaean crust. Mixing with an evolved continental crust is always present. The inferred geotectonic setting is a continental magmatic arc developed on a stretched Archaean and Palaeoproterozoic (Eburnian) crust during the Neoproterozoic. Detrital zircon grains of investigated tillites demonstrate, that in the West African crustal evolution during Eburnian orogenic processes (ca. 1.8-2.2 Ga) in most cases a 2.2 to 4.3 Ga old basement became reworked. Archaean magmas remelted a 2.7 to 3.8 Ga old crust. Zircons with an age of 3.2-3.3 and 3.4-3.5 Ga show a juvenile trend. Two Eburnian zircon grains dated at 2056±34 Ma and 2103±40 Ma imply reworking of pre-existing Hadean crust and show T_{DM} model ages of 4.21 Ga and 4.27 Ga, respectively. Hadean crust existed until ca. 2.0 Ga.

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New P-T-t information on the Münchberg Massif and its eastern neighbourhood results in a better understanding of the early Variscan orogeny

Hans-Joachim MASSONNE[1], Gelareh RAHIMI[1], Florian WAIZENHÖFER[1]

[1]*Institut für Mineralogie und Kristallchemie, Universität Stuttgart, Azenbergstr. 18, D-70174 Stuttgart; e-mail: h-j.massonne@mineralogie.uni-stuttgart.de*

Introduction

Geodynamic scenarios related to the collision of Laurussia and (fragments of) Gondwana, forming the Variscan orogen, depend on numerous information provided by rocks involved in this collision. Among this information, the pressure (P) - temperature (T) - time (t) paths of metamorphic rocks contribute significantly to a better understanding of the evolution of this orogen. In the presented work we have focused on the early evolution of the northeastern portion (Bohemian Massif) of the Variscan orogen. This evolution is believed to have started soon after 400 Ma at the northeastern margin of the Variscan orogen (Massonne, O'Brien 2003, and references therein) according to numerous studies, for instance, in the Polish Sudetes (Góry Sowie) and in Upper Franconia (Münchberg Metamorphic Complex = MMC). Garnet-bearing rocks, which are frequently high-pressure (HP: $P > 10$ kbar) rocks such as eclogites, are widespread in these metamorphic complexes and have attracted our attention. Here, we present new P-T-t data on eclogites and gneisses from the Münchberg Massif and a micaschist occurring at the northern margin of the Fichtelgebirge.

Methods

The bulk-rock compositions of selected metamorphic rocks were determined by X-Ray fluorescence spectrometry (mainly major elements) and laser-ablation ICP mass-spectrometry (trace elements). The compositions of minerals in these rocks were investigated with a CAMECA electron microprobe (EMP). Special attention was given to the chemical zonation of garnet and potassic white mica, for which numerous element concentration maps were produced. The EMP was also used to analyze monazite in particular for its Pb, Th, and U contents. These contents resulted in ages with 1σ-errors often close to 10 Ma for a single monazite analysis.

P-T pseudosections were calculated with the computer program package PERPLE_X for the selected rocks over extended P-T ranges often considering different Fe^{3+} contents in a single rock to optimize the determination of metamorphic P-T conditions. If necessary, the haplogranitic melt model by White et al. (2001) was considered to determine the solidus curve for a specific rock. The contouring of the pseudosections were achieved for molar fractions of garnet components, Si content in white mica, modal content of garnet and additional parameters.

Results

A) Garnet-muscovite-bearing mylonitic paragneiss from the Liegendserie unit of the MMC: Mainly based on the chemical zonation of garnet porphyroblast and smaller garnet, formed later during mylonitisation, and the variable Si content in potassic white mica, the P-T evolution of this rock is characterised by an anti-clockwise path starting at 6 kbar and 600°C. A peak temperature of c. 670°C was reached, resulting in partial melting, followed by HP metamorphism at 12 kbar and 650-670°C accompanied by mylonitisation. The retrograde path passed through P-T conditions of 9 kbar and 610°C. Small oval-shaped, unshielded monazite grains did not yield previously reported early Variscan metamorphic ages despite the intensive deformation of the studied rock at relatively high temperatures, but late Cadomian to early Caledonian protolith ages between ~575 Ma and ~455 Ma. These ages were related to magmatic events in the provenance area, the Armorican Terrane Assemblage (ATA). Thus, the original sediments of the Liegendserie unit were probably deposited in Silurian times. They might be similar to those of the Lower Palaeozoic of (very) low metamorphic grade surrounding the MMC.

B) Other gneisses from the Liegendserie unit and one gneiss from the Hangendserie unit of the MMC: These rocks, which were originally immature sediments according to their bulk-rock compositions, also reached peak P-T conditions of about 12 kbar and 660°C but along a clockwise P-T loop. Again, pre-Devonian monazite ages were obtained but most monazite analyses yielded Devonian ages leading to a population age of 387.3 ± 3.5 (2σ) Ma.

C) Rocks from three eclogite bodies of the MMC (Weißenstein, Fattigau, Oberkotzau): Bulk-rock analyses of the studied eclogites confirm that they were originally basalts/gabbros from the mid-ocean ridge (see Stosch, Lugmair 1990). Based on the chemical zonation of garnet and phengite, peak metamorphic conditions were reached at 26-30 kbar and 670-740°C along clockwise P-T loops. For instance, the deducible prograde path of the Weißenstein eclogite starts at P-T conditions of 17 kbar and 600°C (peak at 26 kbar, 670°C). In all three cases, the prograde path for the studied eclogites points to tectonic (subduction) erosion and subsequent involvement in subduction of an oceanic slab rather than to direct subduction of oceanic crust.

D) Micaschist from the northern margin of the Fichtelgebirge: The studied micaschist was originally a pelitic sediment. On the basis of the chemical zonation of several-mm sized garnets, which are characterized by a foam structure in quartz with garnet plates forming an S in favourable sections, muscovite compositions, and staurolite at the margin of garnet and enclosed in rare andalusite, a clockwise P-T path was constructed. P-T conditions of 9-10 kbar and 535°C were derived for an early metamorphic stage which was followed by a pressure release to 5.5 kbar and 550°C. The final metamorphic P-T conditions were around 3.5 kbar and 580°C. Monazite dating resulted in a more or less continuous age spectrum between 360 and 280 Ma. The younger ages are related to contact metamorphism at 3.5 kbar and subsequent fluid-mediated processes triggered by the intrusion of adjacent granitic magmas close to the Permian-Carboniferous boundary (Siebel et al. 2010). The youngest ages might reflect hydrothermal processes in the Fichtelgebirge area.

Conclusions

Considering previous geodynamic models for the collision of Laurussia with the ATA (e.g. Linnemann, Romer 2010, and references therein) our studied metasediments were deposited at the northern margin of the ATA. Some of these metasediments were brought to great depths (Münchberg Massif) after closure of the Rheic Ocean, probably during the early collision of Laurussia (Avalonian portion = downgoing plate) with the ATA in the time interval 390-375 Ma. Eclogites from the Münchberg Massif, which were taken as witness of the subduction of the Rheic Ocean, were actually tectonically eroded from a deeper portion of the ATA, but involved in the subduction. Their exhumation occurred first in a subduction channel and then in an exhumation channel after coming in contact with the downgoing Laurussia plate (including the deeply buried ATA metasediments).

The previous spreading center of the Rheic ocean had moved southwards to open a new ocean (Neo-Rheic Ocean?) south of the ATA. This ocean probably started to be closed in Devonian times but the final closure and collision of the ATA part of Laurussia and Gondwana occurred in early Carboniferous times (ending around 340 Ma). As a result of this collision, portions of the Laurussia plate were moved northwestwards to form a thick nappe stack to which the nappes of the Münchberg Massif belong to. The studied micaschist was overridden by about 35 km of, thus, thickened crust around 345 million years ago. Low-grade metasediments west of the micaschist locality, however, seem to be overridden by a less thick nappe stack.

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XXIIIrd Meeting of the Petrology Group of the Mineralogical Society of Poland

Subduction systems in the Sudetes and related areas

General session: oral and poster contributions

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Late- and post-orogenic Carboniferous to Permian volcanism in the Intra-Sudetic Basin – new age constraints and tectonic context

Marek AWDANKIEWICZ, Ryszard KRYZA

University of Wroclaw, Institute of Geological Sciences, Department of Mineralogy and Petrology, ul. Cybulskiego 30, 50-205 Wrocław, Poland; marek.awdankiewicz@uwr.edu.pl

Voluminous granitic plutonism and mafic to felsic volcanism were associated with the Variscan collision and orogeny in late Palaeozoic times. The climax of volcanism occurred at c. 299-291 Ma, in the Early Permian, close to the Carboniferous/Permian boundary. However, the onset and timing of the initial, Carbonifeorus volcanism are not constrained well. The Intra-Sudetic Basin, a large intramontane trough in the eastern part of the Variscan Orogen, contains a 11 km thick Carboniferous to Permian siliciclastic succession intercalated with volcanic rocks. This provides a detailed record of late- and post-orogenic sedimentation and volcanism adjacent to the Intra-Sudetic fault, a regional strike-slip zone and a terrane boundary. Based on new SHRIMP zircon ages of 7 representative samples, the emplacement sequence of the volcanic rocks is discussed in the context of the late orogenic magmatic and tectonic processes in the Sudetes region.

The studied volcanic rocks crop out near the town of Wałbrzych and comprise: (1) calc-alkaline rhyodacites, andesites and basaltic andesites that occur mainly as laccoliths, lavas and sills in Visean to Stephanian deposits, and (2) mildly alkaline rhyolitic tuffs, rhyolites and trachyandesites that form a belt of diatremes, dikes and sills in latest Visean to earliest Permian deposits. The calc-alkaline rocks were dated at: 313.0±5.4 (Stara Białka Rhyodacites), 311.0±5.0 (Stary Lesieniec Rhyodacites), 310.0±3.8 (Chełmiec Rhyodacites) and 304.5±3.4 Ma (Nagórnik Andesites); a similar age of 306.1±2.8 was determined earlier for the Sady Górne Rhyodacites. These ages document a Westphalian-Stephanian activity, possibly a prolonged, semi-continuous series of events, or two more distinctive episodes around c. 311 and 305 Ma, beginning with the emplacement of major felsic laccoliths and lavas and followed by the intrusion of minor felsic to mafic sills. The mildly alkaline rocks yielded the ages of: 293.0±4.0 (Trójgarb Rhyolites), 292.8±4.9 and 288.0±4.0 Ma (Rusinowa-Grzmiąca Rhyolites and Trachyandesites). Although the youngest and oldest of these three dates must be treated with caution (due to high U and/or common Pb contents in some of the zircons analyzed), these results confirm the Early Permian emplacement age of the middy alkaline suite, c. 14 My after the calc-alkaline suite. The older ages of c. 311 and 305 Ma for the calc-alkaline rocks compare well to the ages of granitoids in adjacent Karkonosze and Strzegom-Sobótka Massifs, whereas the younger, Permian ages of c. 291 Ma correspond mainly to the regional climax of volcanism recorded in the late/post Variscan sedimentary basins. The discussed Westphalian-Stephanian-Early Permian (sub)volcanism can be linked to a late tectonic activity along the Intra-Sudetic fault, as well as the regional extensional tectonics and the lateral expansion and development of late Variscan intracontinental troughs, the Intra- and North-Sudetic Basins.

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Monazite in mixed magmas of the Strzeblów quarry

Bogusław BAGIŃSKI[1], Justyna DOMAŃSKA[1], Petras JOKUBAUSKAS[1], Ray MACDONALD[1]

[1]*Institute of Geochemistry, Mineralogy and Petrology, Faculty of Geology, University of Warsaw, al. Żwirki i Wigury 93, 02-089 Warszawa; e-mail: b.baginski1@uw.edu.pl*

Monazites of unusually large size (up to 600 μm) and number (up to 100 in a thin section) grew at the interface between intermediate and salic magmas (Turniak et al. 2014) in rocks coming from samples collected in Strzeblów quarry. Their growth was most probably promoted by mixing between the magmas. The monazites also show detailed textural and compositional features related to hydrothermal activity in the host rocks. Within the area of an ordinary thin section located on the boundary between granodiorite/granite and a slightly darker enclave of granodiorite/tonalite composition, we have found up to 100 crystals of monazite (10 microns or bigger). Most of them are located within the rim zone of the enclaves. They show clear oscillatory zoning typical of magmatic origin. Compositional zoning is most prominent in Th content (which in some large crystals varies from 23.8% in the core to 2% Th in the rim). We relate the unusual growth of monazite crystals to the process of magma mixing, which is reflected in plagioclase crystals in the enclaves, showing distinct reversed and/or oscillatory zoning (An_{46} to An_9). Large euhedral or subhedral, patchily zoned, crystals up to 5 mm are sometimes present. There has clearly been movement of these large crystals between the two magmas. The process has been documented from many plutons (for example, reported megacryst movement between melts in the Karkonosze pluton, Słaby et al. 2007). The change of temperature and/or the composition of melt could be responsible for the resorption of many monazite crystals.

More than 20% of monazites show different, later alteration styles. Three general kinds of alteration are dominant:

1) Monazite > Apatite
2) Monazite > Apatite + Allanite
3) Monazite > Apatite + Allanite + Xenotime + a REE phase + U±Th phase

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An incipient study: A multi-faceted thermochronological approach investigating exhumation of UHP terranes within the Seve Nappe Complex, Scandinavian Caledonides

Christopher BARNES[1], Jaroslaw MAJKA[1,2], Katarzyna WALCZAK[1], David SCHNEIDER[3]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland; cjbarnes063@gmail.com*
[2]*Uppsala University, Department of Earth Sciences, Villavägen 16, SE – 752 36 Uppsala, Sweden; jaroslaw.majka@geo.uu.se*
[3]*Department of Earth and Environmental Sciences, University of Ottawa, 25 Templeton St, Ottawa, ON K1N 6N5, Canada*

The Mid-Paleozoic Caledonian Orogeny provides a comprehensive record of a Himalaya-type orogen. Recent discoveries of ultra-high pressure (UHP) metamorphism in the Seve Nappe Complex (SNC) of the Scandinavian Caledonides provide the basis for new investigations into the evolution of subduction - exhumation of the Baltoscandian margin during Caledonian tectonism. Specifically, exhumation of UHP terranes following subduction remains enigmatic; they cannot be explained by buoyancy contrasts within the subduction channel. Instead, exhumation is hypothesized to result from conditions of underpressure developed within the Baltoscandian subduction channel (i.e. the 'vacuum-cleaner' model) resulting from subduction of the overriding Iapetus plate. To investigate this exhumation model, we employ a multi-faceted thermochronological approach to constrain timing and rates of exhumation of these UHP terranes. Recent fieldwork in Norrbotten, Sweden (summer 2016), was conducted to acquire samples from the SNC of: 1) Fresh and retrogressed eclogite for the purpose of conventional U-Pb LA-ICP-MS dating of rutile and titanite coupled with Zr-in-rutile/titanite geothermometry, and U-Pb LA-ICP-MS depth profiling of zircon grains, targeting thin metamorphic rims associated with retrogression of the eclogite during exhumation; 2) Metasedimentary rocks (hosting the eclogite) for the purpose of in-situ $^{39}Ar/^{40}Ar$ dating of white micas that define a pervasive foliation preserved within the metasedimentary host rocks. Development of this foliation has previously been ascribed to exhumation of the UHP terranes. Constraints on timing and rates of exhumation of the UHP terranes, provided by these thermochronometers, will ultimately be combined with the results of studies examining the P-T-t progression, as well as timing of peak metamorphic conditions, to produce models of subduction - exhumation of the Baltoscandian rifted margin. This study will contribute to the global understanding of Himalaya-type orogens.

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Mineralogical characterization of Baroque exterior decorative plasters from the church of the Assumption of the Virgin Mary in Lubiąż (SW Poland)

Wojciech BARTZ[1], Jakub KIERCZAK[1], Maria GĄSIOR[2]

[1] *University of Wroclaw, Institute of Geological Sciences, pl. M. Borna 9, 50-204, Poland, e-mail: wojciech.bartz@uwr.edu.pl*
[2] *Wroclaw University of Technology, Laboratory for Technological and Conservation Research, Faculty of Architecture, ul. Rozbrat 7, 50-334 Wrocław*

Exterior decorative plasters used in the construction of the church of the Assumption of the Virgin Mary in Lubiąż were studied. The aim of this research was to characterize their binder and aggregate, with a particular focus of admixed pigments. Complete characterization of studied materials were carried out using mineralogical methods (polarizing microscopy, X-ray diffraction), thermal studies (digital scanning calorimetry and thermogravimetric analysis) and scanning electron microscopy coupled with energy dispersive spectrometry.

The church of the Assumption of the Virgin Mary belongs to post-Cistercian abbey located in Lubiąż, situated about 50 km northwest of Wrocław. The church was founded by Cistercian monks who came to Lubiąż in 1163. The oldest relics are dated to the Romanesque time, but the main body of the church was erected in Gothic style and completed in the 13th century. Subsequently, numerous reconstructions took place, the most important of which occurred in the first half of the 17th century (in Baroque style).

On the basis of macroscopic observations, different types of multilayered or homogenously-colored plastering mortars were detected. The most common are creamy-white whereas mortars with red or grey/dark-grey color are less common. All of the investigated mortars contain abundant filler, mainly composed of quartz with sparse feldspars and lithic grains, differing in grain-size distribution. Coarse-grained filler is typical for priming layers, whereas the fine-grained filler was found in the decorative finishing layers. Additionally, the red-colored mortars have an admixture of red pigment – hematite (presumably red-ochre), while the grey-colored additions are of fine-grained charcoal and forge scale.

Various types of binders have been identified and characterized: 1) lime binder consisting of calcite (micrite); 2) dolomitic lime binder composed of magnesite with subordinate amounts of hydromagnesite; and 3) hydraulic binder comprising microcrystalline products of the hydration of the Portland cement. Calcareous binder is locally accompanied with small amounts of gypsum. However it is a secondary phase, formed due to surface weathering of decorative plasters.

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Preliminary data on the age of metamorphism of the Rittervatnet unit, Ny Friesland, northern Svalbard

Jakub BAZARNIK[1], Jarosław MAJKA[2,3], Karolina KOŚMIŃSKA[3], Karsten PIEPJOHN[4]

[1]*Polish Geological Institute – Polish Research Institute, 4, Rakowiecka Street, 00-975 Warszawa; e-mail: Jakub.Bazarnik@pgi.gov.pl*
[2]*Department of Earth Sciences, Uppsala University, Villavägen 16, 752-36 Uppsala, Sweden; e-mail: jaroslaw.majka@geo.uu.se*
[3]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków*
[4]*Bundesanstalt fur Geowissenschaften und Rohstoffe, Geologie der Energierohstoffe, Polargeologie, Stilleweg 2, 30655 Hanover, Germany*

The Rittervatnet unit is part of the Atomfjella Complex. It belongs to Svalbard's Eastern Province composed of a thick (c. 18 km) rock sequence of Paleoproterozoic to Ordovician age. The Atomfjella Complex comprises several units built mainly by orthogneisses and psammitic metasediments. The rocks of this Complex build the Atomfjella Antiform, a main ca. 150 km long north-south trending structure (Witt-Nilsson et al. 1998). Structural studies suggest that the Atomfjella Antiform is composed of four thrust sheets with similar granitic basements covered by psammites (Gee, Tebenkov 2004, Hellman et al. 2001).

The Rittervatnet unit comprises quartzites, metapelites, marbles and amphibolites. The rocks belonging to this unit crop out in the southern part of Ny-Friesland, along the southern coast of Mosselbukta. Samples for this study were collected during the CASE 18 expedition to Mosselbukta in 2015. Metasedimentary rocks from the Rittervatnet unit consist of quartz, plagioclase and biotite with minor amount of garnet, ilmenite, magnetite, monazite and zircon. The peak metamorphic assemblage includes Grt+Bt+Q+Pl. The content of Alm in analyzed garnet fluctuates with maximum values in the core; Prp decreases from the core and increases towards the rims; Grs slightly increases towards the rims, while Sps decreases. Conventional geothermobarometry was used for pressure-temperature (PT) estimates. The obtained data suggests PT results of c. 8-11 kbar at 580-700°C.

Chemical monazite dating showed two groups of metamorphic ages: c. 460 Ma and c. 420 Ma. Similar ages were noticed in the Mosselhalvøya Group, the unit under-lying the Atomfjella Complex (Bazarnik et al. 2014).

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Occurrence of moldavites in Pleistocene sediments of SW Poland

Tomasz BRACHANIEC[1], Krzysztof SZOPA[1], Janusz BADURA[2], Łukasz KARWOWSKI[1]

[1]*Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec, Poland; e-mails: krzysztof.szopa@us.edu.pl, tbrachaniec@us.edu.pl, lukasz.karwowski@us.edu.pl*
[2] *Polish Geological Institute – National Research Institute, Lower Silesian Branch in Wrocław, al. Jaworowa 19, 53-122 Wrocław, Poland; mail: janusz.badura@pgi.gov.pl*

Moldavites are German impact glasses which were produced during the Nördlinger Ries impact. The Ries impact event is dated ~14.8 Ma. This implies that all Polish moldavites are parautochthonous. In addition to Miocene Polish tektites, moldavites were also discovered in Pleistocene deposits in the Lasów locality which is located ~8 km north from Zgorzelec (Poland) and Görlitz (Germany), close to the Polish-German border. The sand and gravel outcrop is located on a high river terrace. The moldavite fragments have typical bottle green colour. Their weight is ~0.8 g and are similar in size with moldavites described from the Miocene sediments. Miocene deposits, as well as Pleistocene terraces are the result of fluvial accumulation processes. According to Trnka and Houzar (2002), the brittle character of moldavite glass efficiently constrains the length of fluvial transport. These results suggest that the Polish tektites originated from the upper part of the drainage basin of the Lusatian area. They were probably washed out from the Miocene sediments that filled in structures such as: the Zittau Depression, the Berzdorf-Radomierzyce Depression, the Višňová Depression and the tectonically uplifted Działoszyn Graben.

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Unravelling the evolution of sulfides from spinel peridotite xenoliths hosted in Lower Silesian basanites (SW Poland)

Michał BUKAŁA[1], Jacek PUZIEWICZ[2], Piotr WOJTULEK[2], Magdalena MATUSIAK-MAŁEK[2], Theodoros NTAFLOS[3]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland; michal.bukala91@gmail.com;*
[2]*Institute of Geological Sciences, University of Wroclaw, Maksa Borna 9, 50-204 Wrocław, Poland;*
[3]*Department of Lithospheric Research, University of Vienna, Althanstraße 14, 1090 Vienna, Austria.*

Lower Silesian Cenozoic alkaline rocks belong to NE part of the Central European Volcanic Provice (CEVP). Basanites from Krzeniów (19.57 Ma) and Wilcza Góra (20.07 Ma; K-Ar ages by Birkenmajer et al. 2007) form volcanic plugs rich in peridotitic xenoliths, predominantly of spinel harzburgite composition. The peridotites contain four textural types of accessory sulfides: (1) Type 'e' (*enclosed*) – singular, anhedral grains < 25 μm, enclosed in silicate phases; (2) Type 'f' (*in fractures*) – small (< 5 μm) grains along inclusion trails; (3) Type 'i' (*interstitial*) – rounded to strongly elongated 1-50 μm grains occurring in cracks and fractures of silicate grains; (4) Type 'b' (*blebs*) – relatively large (up to 300 μm in diameter) rounded sulfide blebs, occurring in the solidified melt patches.

Chemical composition of type 'e' sulfides is entirely controlled by Fe-Ni-S system. Differences between samples have not been observed, whereas within the same xenolith, sulfides enclosed in orthopyroxene are enriched in Ni (up to 33 wt.% higher) and Cu (up to 2.44 wt.% higher), compared to those enclosed in olivine. The composition of type – 'i' and 'b' sulfides is controlled by Fe-Ni-Cu-S system. Two compositional groups have been distinguished: (A) Ni-rich (>33.49 wt.% Ni; <31.67 wt.% Fe) and (B) Fe-rich (>35.2 wt.% Fe; <31.7 wt.% Ni). Sulfides from Ni-rich group occur in xenoliths altered by reaction within carbonatitic-alkaline melt, whereas the Fe-rich ones occur in xenoliths affected by "Fe-metasomatism" due to syn-volcanic alkaline silicate melt percolation at mantle depths.

Type 'e' sulfides supposedly are primary and have been entrapped in silicate minerals during dissolution-precipitation process. Type 'i' and 'b' sulfides crystallized from immiscible sulfide melt, unmixed from synvolcanic percolating silicate melt due to T and/or P decrease. Sulfides bulk composition directly reflects type of melt affecting host peridotite. Currently observed assemblages are represented by low-T phases, exsolved from high-T MSS.

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Replacement processes of primary mineralization in the uppermost part of the Kupferschiefer series in SW Poland

Andrzej CHMIELEWSKI[1] Sławomir OSZCZEPALSKI[1]

[1] *Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, ul. Rakowiecka 4, 00-975 Warszawa; email: andrzej.chmielewski@pgi.gov.pl, slawomir.oszczepalski@pgi.gov.pl*

This paper concerns the nature of mineralization in the carbonate rocks of the Zechstein Limestone, in the uppermost part of copper-bearing series within a few areas of the Fore-Sudetic Monocline (Borzęcin, Boruja, Bułaków, Cicha Góra, Pogorzela, Radlin, Świeca, Wiewierz and Wilcze), representing different type of mineral distribution patterns.

Detailed microscopic and electron microprobe examination of the investigated rocks suggests that pyrite occurs mostly as spherules, framboids and tiny euhedral or anhedral crystals as the earliest sulphide formed during early anoxic diagenesis. Pyrite commonly replaces organic matter. Pyritic spherules and framboids are nearly rounded or slightly elongated with smooth or rough surfaces. Some spherules and framboids contain elevated values for Si, Al, K and Ca, which were probably incorporated during the growth of these forms. Individual spherules, framboids and tiny crystals are usually dispersed throughout the examined rocks, but locally, they can be partially or entirely grouped into large grains, clusters, and lenses, and occasionally packed loosely or densely into aggregates.

Pyrite, the primary sulphide, is preferentially replaced by secondary sulphides, including: sphalerite, galena and copper-poor sulphides (chalcopyrite, bornite), followed successively by copper-rich sulphides (covellite, chalcocite), or locally by As-Sb sulphosalts and other minerals: idaite, carrollite, alabandite, nowackite, arsenopyrite, sulvanite, enargite and/or luzonite. The partial to complete replacement textures of pyrite are regularly observed in many different forms. Pyrite-rich samples show the clearest textural evidence of this process, predominantly visible in the uppermost part of the copper-bearing series. Numerous remnants of pyrite are found in the centers of aggregates, clusters or irregular grains consisting of zinc, lead or copper sulphides, indicating that pyrite has been partially transformed into secondary sulphides, although unaffected pyrite grains are also common. Typical textures include pseudomorphs of copper, lead and zinc sulphides after framboidal pyrite. Electron microprobe analysis revealed that outer margins of framboids are composed of Cu, Zn or Pb-rich pyrite, whereas inner zones are represented by pyrite with minor Cu, Zn and Pb admixtures. Pyrite was not recognized as inclusions in any studied minerals, only obvious relics were identified. Furthermore, copper, zinc and lead sulphide grains are larger and more irregular in shape with respect to pyrite. Replacement processes essentially controlled the textural development of secondary mineralization indicating that replacement textures advocate that Cu, Zn and Pb sulphides post-date primary pyrite mineralization.

Replacements of pyrite by Cu, Zn, Pb sulphides, and other minerals, indicate that emplacement of secondary sulphides overlapped deposition of the earliest sulphides, leading to extensive destruction of the primary components. As a result of mineralizing fluids introduced during diagenesis of the host rocks, metal sulphide enrichments were formed in the carbonate rocks of many studied areas. The current location of the altered zone preserves the final extent of upwelling and spreading of mineralizing solutions. There are no secondary enrichments in places where rocks were not affected by fluid/rock interaction and these rocks typically contain unaltered pyrite mineralization.

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Alkali feldspars in Ashua limestones, southern Peru

Justyna CIESIELCZUK[1], Andrzej PAULO[2], Jerzy ŻABA[1], Krzysztof GAIDZIK[1], Grzegorz RACKI[1]

[1]*Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec; e-mails: justyna.ciesielczuk@us.edu.pl, k.gaidzik@gmail.com, jerzy.zaba@us.edu.pl, grzegorz.racki@us.edu.pl*
[2]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al.Mickiewicza 30, 30-059 Kraków, Poland; e-mail: andrzej.paulo@interia.pl*

Authigenic feldspars seem to be frequent in Ashua limestones of different stratigraphic position. In this preliminary study only the most euhedral grains (0.1-0.5 mm) from a site adjacent to a dacite stock were studied in detail. They are of albitic composition with few percent anorthite, randomly distributed within the coarse-grained limestone composed of 85.7% recrystallized calcite, 11.4% authigenic albite, 2.3% quartz and 0.6% stilbite. The presence of zeolite and the hardness of the rock suggest that it was thermally affected. In some other sites hosting limestones and marls do not reveal any sign of thermal influence, though feldspar crystals are overgrown by fibrous calcium carbonate. They form either a lamina between homogeneous micrite limestone and sandy limestone or are dispersed among siliciclastic framework of lithic wackes – sandy marls with carbonate-gypsum cement. In the last case recrystallized outer rim has semi euhedral habit and alkali feldspar composition: Na>K or purely potassic.

The origin and chemical conditions under which alkali feldspars can form in carbonate rocks are not well understood. Low-temperature alkali-feldspar formation in limestone was firstly described at the end of nineteenth century (Daly 1917). Crystallisation in calcareous mud on the sea-floor, when the sediment was not yet consolidated nor deeply buried, was the origin proposed. In the Cieszyn Limestones, southern Poland, authigenic albite occurs as epitaxial overgrowths on detrital feldspars or as a late-diagenetic metasomatic replacement of carbonates in limestone (Wieser 1971). More recent work on alkali feldspars in calcareous rocks has ascribed their low-temperature formation to reaction of brine with siliciclastic debris (Hearn, Sutter 1985; Spötl et al. 1999).

In the Ashua limestones, the feldspar growth seems to have been thermally influenced by the intrusion of dacite. There are no fluid inclusions visible in the albites under the scanning microscope which would suggest an origin from migrating brine.

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Influence of the atmospheric gaseous pollutants (SO_2, NO_2) on heavy metals and free radicals concentration in lichen *Hypogymnia physodes*: Świętokrzyski National Park case study.

Monika CIĘŻKA[1], Rafał TYSZKA[2], Anna ŁUBEK[3], Agnieszka LEWIŃSKA[4], Adam JEZIERSKI[4], David WIDORY[5], Maciej GÓRKA[1]

[1]*Institute of Geological Sciences, University of Wroclaw, Max Born Sq. 9, 50-204 Wroclaw; e-mail:monika.ciezka@uwr.edu.pl*
[2]*Institute of Soil Sciences and Environmental Protection, Wroclaw University of Environmental and Life Sciences, Grunwaldzka 53, 50-357 Wroclaw*
[3]*Department of Botany, The Jan Kochanowski University in Kielce, Świętokrzyska St. 15, 25-406 Kielce*
[4]*Department of Chemistry, University of Wroclaw, Joliot-Curie 14, 50-383 Wrocław*
[5]*GEOTOP/UQAM, Department of Earth and Atmospheric Sciences, 201 ave du Président Kennedy, Montréal H2X 3Y7, Canada*

This study is part of a project that aims at coupling chemical, isotopes and electronic paramagnetic resonance (EPR) analysis of lichen *Hypogymnia physodes* to characterize the anthropopression on the Świętokrzyski National Park (Poland). Lichen samples were collected in 20 locations in February (heating season - h) and June (vegetative season - v) 2013. Results for carbon, nitrogen and sulfur weight percentage concentration are as follow: 35.1-47.0% C (h) and 43.3-49.4% C (v), 0.9-3.1% N (h) and 1.2-2.6% N (v), 0.006-0.137% S (h, adsorbed), 0.006-0.101% S (h, organic), 0.013-0.153% S (v, adsorbed) and 0.069-0.206% S (v, organic), respectively. The corresponding isotope compositions are: -27.5 to -25.6‰ (h) and -28.8 to -25.6‰ (v) for $\delta^{13}C$, -10.9 to -7.2‰ (h) and -12.2 to -7.3‰ (v) for $\delta^{15}N$ and 2.4-4.7‰ (h, adsorbed), 1.9-3.3‰ (h, organic), 1.7-4.7‰ (v, adsorbed) and -0.1-3.1‰ (v, organic) for $\delta^{34}S$, respectively. CO_2, NO_2 and SO_2 concentrations in the air varied as follows: 477-672 ppm (h) and 390-545 ppm (v), 5.8-13.2 $\mu g \cdot m^{-3}$ (h), 0.9-9.4 $\mu g \cdot m^{-3}$ (v), 0.8-14.2 $\mu g \cdot m^{-3}$ (h) and <0.1-1.9 $\mu g \cdot m^{-3}$, respectively. However the fluctuations observed in the concentrations of the main gaseous pollutants (CO_2, NO_2, SO_2) are not coupled with variations of the corresponding isotope signal ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$) in the bioindicators. This is probably caused by homogenous isotope compositions from the sources involved along the year.

While Jezierski et al. (1999) hypothesized that there is a correlation between the NO_2 and SO_2 concentrations in the air and the number of free radicals, our results do not show such relation, which could be explained by the low gas concentration observed. The number of free radicals is negatively correlated with only Fe during the vegetative season (r = -0.49). On the other hand the NO_2 is negatively correlated with the Mn concentrations during the vegetative season (-0.45) while positively with Cu (r = 0.46, v). Additionally SO_2 positively correlates with Cu (0.50, h; 0.48, v). At the same time NO_2 and SO_2 concentration correlates each other during vegetative season reaching r = 0.58.

Moreover during both seasons correlations between Zn and Pb were observed (0.51, h; 0.69, v) that can be linked to the presence of Zn-Pb ore deposits in the vicinity.

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Subduction and eduction of a continental margin in the southern Scandinavian Caledonides: Insights from ultrahigh pressure metamorphism, late orogenic basins and 3D numerical modelling.

Simon CUTHBERT[1], Hannes BRUECKNER[2], Andrew BOTTRILL[3,4], Jeroan VAN HUNEN[4], Mark ALAN[4]

[1]*School of Science, University of the West of Scotland, Paisley PA1 2BE, UK; simon.cuthbert@uws.ac.uk*
[2]*Lamont-Doherty Earth Observatory of Columbia University, New York, USA*
[3]*Ikon Science Ltd, Durham DH1 5TS, UK*
[4]*Department of Earth Sciences, Durham University, Durham, UK*

The Scandinavian Caledonides (SC) represent a plate collision zone of Himalayan style and scale. Three fundamental characteristics of this orogen are: (1) early foreland-directed, long-distance tectonic transport and stacking of nappes; (2) late and wholesale reversal of tectonic transport; (3) ultrahigh pressure metamorphism of felsic crust derived from the underthrusting plate at several levels in the orogenic wedge and below the main thrust surface, indicating subduction of continental crust into the mantle. The significance of this for crustal evolution is the profound remodelling of continental crust, direct geochemical interaction of such crust and the mantle, and the opening of accommodation space trapping much eroded clastic sediment within the orogen. Hence, understanding the fundamental causative tectonic processes is a priority for research. The orogenic wedge of the SC was derived from the upper crust of the continental margin of Baltica (which seems to have been a hyper-extended passive margin with only limited magmatism) and, at higher levels, terranes derived from a complex assemblage of outboard arcs and intra-oceanic basins and the Laurentian margin. Nappes derived from Baltica continental crust were subducted, in some cases to depths sufficient to form diamond. These then detached from the upper part of the down-going plate along major thrust faults, at which time they ceased to descend. Subduction of the remaining continental margin continued below these nappes, possibly driven by slab-pull of the previously subducted Iapetus oceanic lithosphere and metamorphic densification of subducted felsic continental margin. 3D numerical modelling shows that if a continental corner or promontory enters the subduction zone, the continental margin descends to greater depths and its thermal evolution is consistent with UHP metamorphic assemblages recorded in the southern part of the SC. Furthermore, a tear initiates at the promontary tip along the ocean-continent junction and propagates rapidly along the orogen. The buoyant upthrust of the subducted margin can then lead to reversal of the motion vector of the entire subducting continent, which withdraws the subducted margin out of the subduction channel (“eduction”). Because of the diachroneity of slab failure, the continent also rotates, which causes the eduction vector to change azimuth over time. These model behaviours are consistent with the late orogenic structural evolution of the southern SC. Finally, the traction of a large educting (or possibly extruding) mass of continental margin against the overlying orogenic wedge may have stretched and ruptured the wedge, resulting in the opening of the Old Red Sandstone molasses basins now outcropping along the southern Norwegian coast.

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Dunite channels in lithospheric mantle peridotites beneath Grodziec (Lower Silesia, SW Poland)

Mateusz ĆWIEK[1]

[1]*University of Wrocław, Institute of Geological Sciences, Pl. M. Borna 9, Wrocław, Poland; email: mateusz.cwiek@ing.uni.wroc.pl*

Nephelinite from Grodziec (Lower Silesia, SW Poland contains numerous, 2-7 cm long peridotite xenoliths, mostly of spinel lherzolite composition. The content of forsterite in olivine divides xenoliths in two groups: A (Fo=91.8-89.3), consisting of lherzolites and subordinated dunites plus harzburgites, and B (Fo=85.2-86.1), consisting of dunites and wehrlites. The xenoliths of olivine clinopyroxenites and clinopyroxenites are classified as group C (Fo=78.8-86.6%). The rocks of group A plot into OSMA field of Arai (1994). Group B xenoliths are adcumulative dunites and wehrlites. Their olivine contains 0.22-0.35 wt.% NiO. Orthopyroxene is absent, clinopyroxene occurs both in dunites (2-6 vol.%) and wehrlites (15 vol.%). Clinopyroxene has relatively low Mg# (0.88-0.86), high LREE content (La_N/Lu_N =4.07-4.15) and occurs in interstices. Spinel has broadly varying Cr# (0.13-0.67). Cumulative olivine pyroxenites and clinopyroxenites of group C consist of clinopyroxene (Mg# 0.80-0.86; La_N/Lu_N=1.96-3.10) olivine (NiO=0.08-0.20 wt.%) and Mg, Al-rich spinel (Mg# 0.58-0.67).

Dunites can be product of extensive melting or result of reaction of harzburgite with silicate melt, leading to dissolution of orthopyroxene and crystallization of olivine (Kelemen, 1990). Replacive dunites formed in such the reaction are commonly described from ophiolitic complexes and interpreted as channels where silicate melt percolated through peridotite. Grodziec group B xenoliths resemble replacive dunites (lack of orthopyroxene, relatively low forsterite and NiO in olivine, LREE enrichment in clinopyroxene). The REE/trace element patterns of clinopyroxene from both group B and C show that the mineral crystallized from melt similar to the host nephelinite. This suggests that the group C clinopyroxenites originated due to crystal settling from the nephelinite melt in places, where its migration through mantle peridotites was temporarily stopped, and the group B wehrlites and dunites originated by reaction of harzburgite host with nephelinite melt. Thus, they formed the "dunite channels" in the SCLM beneath Grodziec, which originated at the time of Cenozoic volcanism.

Xenoliths similar to replacive dunites occur also in other sites in Lower Silesia, but were not considered as fragments of dunite channels. Replacive dunites from Grodziec constitute 13.6% of all xenoliths, fitting observation that dunite channels constitute about 5-15 vol.% of oceanic upper mantle (Kelemen et al., 1995). The proportions of dunitic and peridotitic xenoliths from other localities in Lower Silesia are similar, which suggests that dunitization process possibly is common in SCLM beneath the region.

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Fluid inclusions in Cr-spinel from the Braszowice-Brzeźnica high-Al chromitites (the Central Sudetic ophiolite)

Katarzyna DELURA[1]

[1]_Faculty of Geology, University of Warsaw, al. Żwirki i Wigury 93, 02-089 Warszawa; e-mail: k.delura@uw.edu.pl_

The Braszowice-Brzeźnica Massif (BBM) consists of ultramafic-mafic rocks and is treated as one of the fragments of the Central Sudetic ophiolite. Its ultramafic rocks, mostly serpentinized, comprise harzburgites, lherzolites, dunites with intercalations of chromitites, that correspond to the upper mantle tectonite unit as well as the transitional zone of the ophiolitic sequence.

The BBM chromitites form rare small elongated bodies within the olivine-tremolite rocks. They display variety of textural types, showing a wide spectrum of Cr-spinel to chlorite matrix ratios as well as the spinel grain sizes. The Cr-spinel grains are non- to moderately altered (transparent in polarized light). The alteration rims, composed of "ferrichromite", are usually narrow and opaque. The chemical composition of the non-altered Cr-spinel allows to distinguish two compositional groups (mainly on the basis of Al, Cr and Ti content) that cannot be ascribed to the specific textural variety (Delura 2012).

The fluid inclusions have been observed within the several non-altered Cr-spinel grains. The two types of inclusions can be distinguished on a textural basis (Roedder 1984):

"Primary", one- (liquid) or two-phase (liquid-gas) inclusions, that are widely scattered in the central parts of Cr-spinel grains, surrounded by the inclusion-free zone. They are characterized by rounded or elongated shapes and sizes of 2-10 μm.

Secondary, two-phase, liquid-gas inclusions, that form "trails", usually along the Cr-spinel grain regenerated cracks. They display irregular sizes (1 up to 20 μm) and shapes (rounded, elongated, ameboidal).

Their presence or type not depends on the chemical composition of the Cr-spinel grain. No negative crystal shape fluid inclusions have been observed in the BBM Cr-spinel grains.

Primary and secondary, two-phase, low salinity aqueous inclusions with variable CH_4 and CO_2 contents have been reported within Cr-spinels from many podiform chromitite localities (Al-Boghady, Economou-Eliopoulos 2005) but it is for the first time at the BBM chromitites. Their presence might indicate fluid saturation system during the chromitite crystallization and tectonic transport within the mantle tectonites unit. Although, more detailed study is needed to describe their composition and define these processes in detail.

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Mariupolite – the imprints of alteration in subsolidus conditions

Magdalena DUMAŃSKA-SŁOWIK[1], Adam PIECZKA[1], Wiesław HEFLIK[1]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland, e-mail: dumanska@uci.agh.edu.pl*

Mariupolite, a silica-undersaturated miaskitic nepheline syenite, only covers a small area (ca. 5-10%) of the alkaline Oktiabrski Massif in south-eastern Ukraine. Albite, nepheline and aegirine are its main components, whereas zircon, pyrochlore, sodalite, natrolite, cancrinite, K-feldspar, annite, britholite-(Ce), fluorite, calcite, magnetite, and hematite make up its accessory phases.

Mariupolite exhibits many traces of alterations in the subsolidus resulting from metasomatic fluids. Two types of alteration processes induced by alkali metasomatism ($Na + Ca + Cl + F + H_2O$) were distinguished within mariupolite: (1) crystallization of hydrothermal cancrinite, calcite and fluorite under action of Ca^{2+}, F^- and CO_3^{2-} present in the fluid and (2) sodalitization of nefeline and possibly albite, connected with formation of secondary natrolite due to action of high Na^+, Cl^- and H_2O in the fluids. In metasomatized mariupolite, the first type of alteration is characterized by small patches rich in calcite, cancrinite, fluorite, and small inclusions of parasite-(Ce) and bastnäsite-(Ce). Probably during that stage of the rock evolution, fluorapatite and fluorbritholite-(Ce) were partially replaced either by the same phases with a new composition or by secondary monazite-(Ce) and fluorite. The second type of alteration resulted in the development of perthite exsolution textures and albitization of K-feldspars. During this type of metasomatosis, sodalite occured as a replacement phase after nepheline and albite, whereas natrolite and some amounts of K-feldspar formed as by-products of this transformation in the subsolidus. The local replacement of magnetite by hematite also occurred at this time, during the fenitization process (Dumańska-Słowik et al. 2016).

The fluid-mediated coupled dissolution-reprecipitation process also affected primary zircon and pyrochlore. The last, but not least mineral containing relatively high SiO_2 concentration (up to 13.01 wt.%), manifests the significant role of Si in high temperature juvenile fluids with high pH and Na, Ca and F activities.

Based on petrography of mariupolite, it can be concluded that metasomatic alteration involved an earlier pervasive Ca- and CO_3^{2-}-rich fluid with some quantities of F^-, and REEs, followed by alkali- and chlorine-rich hydrous action (Dumańska-Słowik 2016).

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Fluid-rock interactions during metasomatism of metapelites from northern Spitsbergen

Karol FAEHNRICH[1], Karolina KOŚMIŃSKA[1], Jarosław MAJKA[1,2], Maciej DWORNIK[1]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków, Poland; karolfaehnrich@wp.pl*
[2]*Department of Earth Sciences, Uppsala University, Villavagen. 16, 752 36 Uppsala, Sweden*

Fluid-rock interactions are a driving force for various mineral replacement reactions. They may lead to changes in chemical composition of rock or its portions, thus enabling element redistribution within the crust. In this contribution we present in depth assessment of metasomatic reactions affecting metapelites from northern Spitsbergen.

In the studied samples zonation of metasomatic changes is apparent with the most intense alterations near the fractures (in this case fluid pathways). Through comparison of the parent rock with the most altered sample we can distinguish and characterize reactions that were fluid driven. Metamorphic assemblage consists of Grt-Bt-Qtz-Pl. Due to metasomatism, biotite breaks down into chlorite, K-feldspar and titanite. Chlorite is classified as brunsvigite based on the Hey (1954) diagram. Volume of main rock-forming minerals was estimated using point count technique and image analysis.

Elements redistribution during biotite-chlorite reaction has been studied using Gresen's (1967) approach and the isocon method (Grant 1986). Obtained results show that amount of water must have increased in the system by at least 8% in order to form 2.4 vol.% of chlorite as observed in the thin sections. Furthermore, magnesium and iron must have been introduced, while titanium and potassium released (resulting in formation of titanite and K-feldspar) during this reaction. Using concentration ratio diagram (Ague 1994) for the whole rock composition we conclude that mainly potassium has been removed from the system (decrease of ca. 15%) whereas magnesium introduced (increase of ca. 15%) with the aqueous fluid.

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High-pressure leucogranulites of the Orlica-Śnieżnik Dome (Bohemian Massif, central Europe): a window into deep melting.

Silvio FERRERO[1,2], Bernd WUNDER[3], Katarzyna WALCZAK[4], Patrick O´BRIEN[1], Martin A. ZIEMANN[1], Markus WÄLLE[5], Laurent REMUSAT[6]

[1]*Institut für Geowissenschaften, Universität Potsdam, D-14476, Golm, Germany*
[2]*Museum für Naturkunde (MfN), Leibniz-Institut für Evolutions- und Biodiversitätsforschung, 10115 Berlin, Deutschland*
[3]*Helmholtz-Zentrum Potsdam, GFZ, D-14473 Potsdam, Deutschland*
[4]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków, Poland*
[5]*Swiss Federal Institute of Technology (ETH), 8092 Zürich, Switzerland*
[6]*Muséum National d'Histoire Naturelle, IMPMC, UMR CNRS 7590, 75005 Paris, France*

High pressure granulites are a common rock type in the Variscan terrains throughout Europe. The Orlica-Śnieżnik leucogranulites contain grossular-rich garnet, kyanite and ternary feldspar in a leucocratic matrix with quartz+K-feldspar+plagioclase. The garnet grew as result of partial melting and contains droplets of crystallized anatectic melt (nanogranites). Such inclusions "portray" faithfully the composition of the melt generated at depth, thus providing an unprecedented chance to elucidate the melting mechanisms operating in deeply subducted crust. Geothermobarometry and piston cylinder experiments pinpoint the partial melting event near or at the metamorphic peak experienced by the rock, i.e. at T≥ 875°C and 2.7 GPa. The resultant melt is metaluminous, and contained approximately 6-6.5 wt% H_2O, as consistently shown by NanoSIMS and Raman analyses on re-homogenized inclusions. Calcite is present throughout the crystallized inclusions: CO_2 was likely present in the original melt in amounts of ≤0.6 wt% or 6000 ppm (mass balance calculation). The correspondence between our natural data and the published experimental results suggests that nanogranites did not lose any fluid to the matrix surrounding the garnet. Further support is provided by the occurrence of rare polymorphs of albite, K-feldspar and quartz; namely kumdykolite, kokchetavite and cristobalite in nanogranites. Such phases confirm that after formation, nanogranites acted as natural "pressure vessels" and remained completely isolated from the changes undergone by the surrounding rock, sheltered by the host garnet. These nanogranites are more enriched in LILE and LREE (average La_N=139) than analogous inclusions in metapelites, possibly because the magmatic protolith of these rocks was at least partly anatectic in origin. The abundance of Ba, Sc, V and Zn suggests the involvement of biotite in the melting reaction, despite the absence of residual biotite in garnet.

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Prograde metamorphic history preserved in mica schists from the Kamieniec Metamorphic Belt (Bohemian Massif, Fore-Sudetic Block) based on quantitative pressure-temperature path from garnet zoning.

Marcin GOLEŃ, Jacek SZCZEPAŃSKI[1]

[1]*Institute of Geological Sciences, University of Wrocław, Pl. M. Borna 9, 50-204 Wrocław, Poland, e-mail: Piotr.slomski@uwr.edu.pl, jacek.szczepanski@uwr.edu.pl.*

The Kamieniec Metamorphic Belt (KMB) situated in the Fore-Sudetic Block is defined by several small outcrops of crystalline basement located between Kamieniec in the south and Księginice Wielkie in the north. The Belt is composed of a volcano-sedimentary succession dominated by mica schists. These rocks bear an imprint of Variscan tectonometamorphic reworking. Pressure-temperature (P-T) conditions of these events were previously estimated at ca. 550-590^{o}C and 7.5 up to 12 kbars. For the purpose of this study we examined two mica schist samples collected from the middle part of the Kamieniec Metamorphic Belt in the vicinity of Stolec and Baldwinowice. The samples are characterized by garnet-muscovite-biotite-plagioclase mineral assemblage. The investigated schists contain compositionally zoned garnet grains with dominant almandine (50-73%), minor spessartine (8-23%) and grossular (5-23%) and subordinate pyrope (3-8%) components. Core-to-rim profiles of garnet porphyroblasts typically display a remarkable increase in almandine, a slight increase in pyrope, roughly constant grossular content dropping at the outer rim and spessartine decrease. We interpret garnet zonation patterns as due to bulk-rock depletion caused by fractional garnet crystallization and therefore reflecting prograde metamorphism. However, some garnets from sample collected near Baldwinowice display rims characterized by slight increase of spessartine component, which may be attributed to resorption related to retrograde cation exchange. We excluded this part of garnets from further thermodynamic modelling. Results of our thermodynamic calculation performed using Theriak-Domino software (de Capitani, Petrakakis 2010) and fractionation model proposed by Evans (2004) show that garnet crystals in the examined samples started to grow at similar P-T conditions at 520°C and 6.3 kbar, whereas peak of metamorphism was reached at 565°C and 7.5 kbar. Obtained results indicate simple prograde P-T path and common P-T history of examined samples, thus most probably representing fragment of the same tectonic unit.

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Pattern of *n*-alkanes distribution characteristic for terrestrial organic matter from the Ediacaran sedimentary rocks of the East European Platform

Magdalena GORYL[1], Leszek MARYNOWSKI[2]

[1]*Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Krakow, Senacka St. No. 1, 31-002 Kraków*
[2]*Faculty of Earth Sciences, University of Silesia, Będzińska St. 60, 41-200 Sosnowiec, Poland; e-mail: leszek.marynowski@us.edu.pl*

n-Alkanes and *n*-fatty acids are common constituents of recent and ancient sedimentary organic matter (OM). Their distribution in case of marine and terrestrial OM differs significantly. Marine algae and bacteria generate short-chain *n*-alkanes with preponderance of C_{17} and C_{19} carbon atoms in the molecule, while terrestrial higher plants (especially leaf epicuticular waxes) characterized by occurrence of long-chain *n*-alkanes and *n*-fatty acids with maximum between C_{23} and C_{29} and C_{22} and C_{30} carbon atoms respectivelly. Moreover, terrestrial OM characterized by significant predominance of high molecular weight odd-carbon-numbered *n*-alkanes and even-carbon-numbered *n*-fatty acids. Here we report the significant prevalence of long-chain *n*-alkanes and *n*-fatty acids with *n*-C_{25} maximum for *n*-alkanes and *n*-C_{24} maximum for *n*-fatty acids from the Ediacaran thermally immature sedimentary rocks of the Wołyń and Petersburg areas. Carbon preference index (CPI) values are much higher than 1 but differs between *n*-alkanes and *n*-fatty acids. For *n*-alkanes CPI values are 1.5 in avarege while in case of *n*-fatty acids these values oscillating around 2. Such values are typical rather for terrestrial than marine OM, seems to be unusual for the Ediacaran sedimentary rocks. However, Ficken et al. (2000) show that submerged/floating aquatic macrophytes generate long-chain *n*-alkanes, similar to these found in the Ediacaran sedimentary rocks. Therefore we conclude that OM from aquatic macrophytes can be responsible for occurrence of long-chain *n*-alkanes and *n*-fatty acids in the investigated Ediacaran clays, deposited in relatively shallow tropical sea. Moreover, our finding questions the utility of the CPI formula as diagnostic for terrestrial higher plants when its values are much higher than one.

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Five-year record of stable sulphur isotope compositions in precipitation reveals multi-seasonal pattern (Wrocław, SW Poland)

Maciej GÓRKA[1], Grzegorz SKRZYPEK[2], Stanisław HAŁAS[3], Mariusz-Orion JĘDRYSEK[1], Dariusz STRĄPOĆ[4]

[1]*Institute of Geological Sciences, University of Wrocław, Cybulskiego 30, 50-205 Wrocław, Poland; e-mail: MG maciej.gorka@uwr.edu.pl, MOJ mariusz.jedrysek@uwr.edu.pl*
[2]*West Australian Biogeochemistry Centre, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia; e-mail: GS grzegorz.skrzypek@uwa.edu.au*
[3]*Institute of Physics, Marie Curie-Skłodowska University, Marii Curie-Skłodowskiej 1, 20-031 Lublin, Poland; e-mail: SH stanislaw.halas@poczta.umcs.lublin.pl*
[4]*Geoservices A Schlumberger Company, 127 avenue du Bois de la Pie, 95971 Roissy, France; e-mail: DS DStrapoc@slb.com*

The stable sulphur and oxygen isotope compositions of sulphates in precipitation have been widely used to identify sources of atmospheric pollution. However, the majority of previous studies have only revealed seasonal trends as they have usually been conducted over relatively short time periods. Here, we present results for 179 samples from a continuous five-year, event-based monitoring conducted in Wrocław (SW Poland). The $\delta^{34}S$ (SO_4^{2-}) values vary from 0.3 to 5.4‰ (mean 2.8±0.9‰) whereas $\delta^{18}O$ (SO_4^{2-}) values vary from 4.7 to 19.1‰ (mean 13.5±2.0‰). The $\delta^{18}O$ (H_2O) values range between -17.8 and 0.0‰ (mean -8.5±3.8‰) and δ^2H (H_2O) values range between -127.2 and -1.9‰ (mean -56.7±27.2‰) forming the Local Meteoric Water Line of $\delta^2H = (6.91 \pm 0.25) \times \delta^{18}O + 2.4 \pm 2.4$. The majority of sulphates in precipitation observed over the sampling period (2004-2009) were of an anthropogenic origin. The contribution of marine sulphur was usually negligible and never exceeded 20%. The relative contribution of primary high-temperature sulphates was lower than secondary low-temperature sulphates and varied between 9.7 and 48.8% of the total measured sulphates load. The $\delta^{34}S$ (SO_4^{2-}) in precipitation displays, not reported before, multi-seasonal oscillations with amplitude of ±2‰. Hence, the initially observed trend (1993-95) in continuously increasing $\delta^{34}S$ (SO_4^{2-}) values (Jędrysek 2000) may belong to a larger scale multiseasonal cycle. This new evidence needs to be considered with caution while analysing trends from short-term observations.

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Exploring the physical constraints for thrust emplacement in the Swedish Caledonides: a pressure-temperature profile through the Lower Seve Nappe based on the COSC-1 drill core

Johanna HOLMBERG[1], Sofia KORHONEN[1], Iwona KLONOWSKA[1], Jarosław MAJKA[1-2]

[1]*Department of Earth Sciences, Uppsala University, Villavägen 16, 752 36 Uppsala, Sweden; e-mail: Johanna.Holmberg.1894@student.uu.se*
[2]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków, Poland; e-mail: jaroslaw.majka@geo.uu.se*

Defining the temperature, pressure and fluid regime that a rock has experienced is essential for understanding crustal evolution. Continuously sampled sections through (parts of) the continental crust are rare. Even worse is the situation in major mountain belts, i.e. the areas where key processes of crustal evolution act. However, recently the COSC-1 (Collisional Orogeny in the Scandinavian Caledonides) scientific drilling project achieved a continuous drill core through the lower part of a hot allochthon in a deeply eroded (to mid-crustal levels) major Paleozoic mountain belt, the Scandinavian Caledonides. The drilling provided us with unique material for the study of the pressure-temperature (P-T) structure of this critical allochthon in a collisional orogeny. Thus, processes that are postulated to occur at unreachable depth, for *in-situ* investigations, in present mountain belts (e.g. Himalayas).

We aim to construct a detailed P-T profile along the COSC-1 drill core to better understand the structure of the hot allochthon (in the Lower Seve Nappe) and how the processes (mechanical, chemical) that were active during the emplacement of this hot allochthon were depending on these physical constraints. We also expect that this work will provide clues on the formation of late porphyroblasts in mylonites, like those that we observe in the lowermost part of the drill core: garnet, and where it is absent pervasive magnetite mineralization. The work in this project is based on a combination of established and innovative methodologies including in-situ P-T estimates (based on Raman-band shifts of quartz inclusions in garnet and titanium concentrations in quartz) and quartz fabric analyses.

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Cadomian subduction system in the Sudetes: vestiges in the core and mantle units of the Orlica-Śnieżnik dome (Bohemian Massif)

Sławomir ILNICKI[1], Jacek SZCZEPAŃSKI[2], Christian PIN[3]

[1] *University of Warsaw, Faculty of Geology, Institute of Geochemistry, Mineralogy and Petrology, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland; e-mail: slawomir.ilnicki@uw.edu.pl*
[2] *Institute of Geological Sciences, Faculty of Earth Science and Environmental Management, University of Wroclaw, Pl. Maksa Borna 9, 50-205 Wrocław, Poland; js@ing.uni.wroc.pl*
[3] *Département de Géologie, C.N.R.S. and Université Blaise Pascal, 5 rue Kessler, 63038 Clermont-Ferrand Cedex, France; C.Pin@opgc.univ-bpclermont.fr*

The core of the Orlica-Śnieżnik dome (OSDC) and its western and southern mantle (the Nové Město and Zábřeh units, respectively, OSDM hereafter) preserve supracrustal successions subsequently metamorphosed during the Variscan convergence. Several geochemical features coupled with the available estimations of maximum depositional age show that metasedimentary successions of the OSDC (interpreted as the easternmost extension of the Saxo-Thuringian zone) were formed in different tectonic environments: supra-subduction zone related to Cadomian magmatic arc (the Młynowiec formation, ca. 560 Ma), the post-Cadomian incipient rift basin with infill from the eroded newly-formed orogen (the Stronie formation, ca. 530 Ma), a shallow-water passive margin basin fed with quartz-rich detritus, akin to Early Ordovician Armorican Quartzites (the Goszów quarzites, ca. 490 Ma). Moreover, metabasalts which were emplaced coevally with the accumulation of the Stronie formation show diverse geochemical features comprising variously enriched N-MORB-like tholeiites, OIB-like alkaline and depleted tholeiitic rocks. They reflect metasomatic processes affecting depleted mantle (input from slab-derived melts or fluids, sub-slab asthenospheric alkaline melts) over an active yet gradually vanishing subduction zone suggesting a vestigial back-arc basin as the most probable tectonic setting for the metabasites. Likewise, metabasites present in the volcano-sedimentary successions of the OSDM are also variably enriched (intermediate between N-MORBs and E-MORBs or E-MORBs and OIBs) and show similar heterogeneous metasomatic enrichment of their respective shallow-seated depleted mantle sources. However, in the OSDM rocks chemically similar to boninites and low-Ti island arc tholeiites appear. The presence of these rare lithologies links the OSDM with the Teplá–Barrandian basement and the Cadomian volcanic arc preserved there in its SE part.

Changes in depositional tectonic setting of the sedimentary sequences, contrasting back-arc basin- and within-plate-style of enrichment of mantle sources to the metabasites in the OSDC and OSDM, the presence of boninite-related rocks in the latter apparently relate the studied rock series with the episodes of extinction of the subduction zone activity at the end of the Cadomian orogeny triggered by ridge subduction, followed by slab retreat and break-off, and incipient Early Palaeozoic rifting. Though now juxtaposed during Variscan convergence, the studied members of the OSD originally formed different parts of the peri-Gondwanan belt and provide an important insight into Cadomian and post-Cadomian development of the Bohemian Massif.

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Corundum-bearing eclogites from Bystrzyca Górna (Góry Sowie Massif, SW Poland): a preliminary report.

Sławomir ILNICKI[1], Eligiusz SZEŁĘG[2], Adam PIECZKA[3], Krzysztof NEJBERT[1], Adam SZUSZKIEWICZ[4], Krzysztof TURNIAK[4]

[1] *University of Warsaw, Faculty of Geology, Institute of Geochemistry, Mineralogy and Petrology, Żwirki i Wigury 93, 02-089 Warszawa, , Poland; e-mail: slawomir.ilnicki@uw.edu.pl*
[2] *University of Silesia, Faculty of Earth Sciences, Department of Geochemistry, Mineralogy and Petrography, Będzińska 60, 41-200 Sosnowiec, , Poland*
[3] *AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Department of Mineralogy, Petrography and Geochemistry, Mickiewicza 30, 30-059 Kraków, Poland*
[4] *University of Wrocław, Institute of Geological Sciences, Cybulskiego 30, 50-205 Wrocław, Poland*

The Sowie Góry Massif is composed predominantly of gneisses and migmatites which host amphibolites, meta-ultramafites and minor granulitic rocks. Eclogites rarely appear in the massif either as relics in amphibolites (e.g. in the Piława Górna quarry) or as small bodies. One of them, located near Bystrzyca Górna, was selected for the present study. The rock is strongly yet variously retrogressed and contains garnet, clinopyroxene, calcic amphibole, plagioclase and rutile. As accessory phases biotite, titanite, ilmenite, chromian spinel and corundum are present. The least retrogressed samples have symplectites of diopside and plagioclase in which clinopyroxene is partly replaced by amphibole. The isometric, anhedral to subhedral grains of garnet reach up to 3-4 mm in diameter. The crystals are surrounded by a thin double-layer comprising tiny crystals of amphibole, chlorite and unidentified silicate, and then enveloped by a coarser amphibole-plagioclase corona. The crystals in corona are elongated, oriented radially to the garnet and separate it from symplectitic matrix. In samples strongly affected by retrogression amphiboles recrystallised to coarse-grained and form amphibole-plagioclase aggregates. Porphyroblasts of garnet contain randomly distributed inclusions of omphacite (X_{jd} up to 0.23-0.24), amphibole, plagioclase and rutile. The observed textures suggest that the original eclogite was essentially bi-mineral (garnet and omphacite) with accessory rutile and presumably SiO_2 phase which could have been consumed during omphacite breakdown.

Preliminary conventional geothermobarometric estimations have indicated that the first metamorphic episode took place at pressures not lower than 14.0-14.2 kbar at temperatures of 660-800°C. This event was followed by omphacite breakdown and then corona formation under amphibolite facies conditions (8.4-7.7 kbar at 670-630°C). At roughly the same conditions (6.3-8.0 kbar at 660-730°C) amphibole crystals grew at the expense of symplectitic clinopyroxene. These results suggest that the P-T path followed a nearly isothermal decompression, similar to that reported for the Pilawa Górna eclogites (Ilnicki et al. 2012). However, in the case of the studied rock a pressure drop is much smaller presumably due to either strong post-peak re-equilibration of the HP assemblage or shallower crustal levels reached on prograde path than other HP rocks in the block.

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The monazite geochronology of tectonometamorphic events in the Góry Sowie Massif, Sudetes

Mirosław JASTRZĘBSKI[1], Bartosz BUDZYŃ[2], Andrzej ŻELAŹNIEWICZ[1], Gabriela A. KOZUB-BUDZYŃ[3]

[1]*Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Wrocław, ul. Podwale 75, PL-50449 Wrocław, Poland; e-mail: mjast@interia.pl, pansudet@pwr.edu.pl*
[2]*Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Kraków, ul. Senacka 1, PL-31002 Kraków, Poland; e-mail: ndbudzyn@cyf-kr.edu.pl*
[3]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Krakow, Poland: lato@agh.edu.pl*

In the Sudetes, the early Variscan Góry Sowie Massif (GSM) is mainly composed of multiply deformed and variously migmatized gneisses along with subordinate amphibolites, felsic granulites and scarce metaperidotites (Żelaźniewicz 1990). In the GSM and in adjacent fragments of the Sudetic Ophiolite and the Kłodzko Metamorphic Massif, tectonometamorphic processes waned by the late Devonian and since then the units were exposed at the surface, thus prior to all other Sudetic units. The previous geochronology revealed that common amphibolite facies progressive migmatization in the GSM gneisses and subsequent cooling occurred between 384-360 Ma (U-Pb monazite, xenotime and Rb-Sr: van Breemen et al. 1988; Bröcker et al. 1998), whereas the granulites underwent a HT-HP event at c. 400-390 Ma, followed by 385-370 Ma amphibolite overprint as shown by U-Pb, Ar-Ar, Sm-Nd and Rb-Sr data (O'Brien et al. 1997; Bröcker et al. 1998; Marheine et al. 2002; Gordon et al. 2005; Kryza, Fanning 2007). Given a broad mylonitic contact between granulites and migmatitic gneisses, a tectonic emplacement of the former in the latter rocks at shallower depths was proposed (Żelaźniewicz 1985). However, some authors assume that all rocks in the GSM underwent granulite facies metamorphism and then reequilibrated at the amhibolite facies conditions (Kryza, Fanning 2007). This study was aimed to test the two options and provide more detailed time constraints on 1) the HT-HP event in the granulites, 2) age signature from the retrograde mylonitized granulites, and 3) record of possibly earlier granulite metamorphism in the amphibolite facies migmatitic gneisses. The electron microprobe (EMP) Th-U-total Pb dating of monazite was performed in-situ in distinct zones of monazites from four selected rocks of the GSM. Two samples represent felsic granulites exposed by the Fregata hostel (at Jezioro Bystrzyckie) near Zagórze Śląskie, with variable record of late- to post-granulite facies mylonitization. The other two samples are a coarse-grained, layered migmatitic gneiss from Piława Górna and a pelitic biotite gneiss from Jugowice.

The monazite grains in a fine-grained, weakly foliated granulite (Qtz-Grt-Ky-Pl) are relatively homogeneous showing no distinct zoning in X-ray compositional maps, and yielded weighted average age 389 ± 3.7 Ma (n = 45, MSWD = 1.01). The peak of granulite facies metamorphism was estimated at 900-1000ºC (Kryza et al. 1996; O'Brien et al. 1997), which was higher than the monazite closure temperature and exceeded by 200-300°C the peak temperature in gneisses. Therefore, the obtained age most likely reflects timing of late stage of the peak conditions recorded in the granulites. The second granulite sample

(Qtz-Grt-Ky-Pl-Bt-Rt) shows stronger mylonitic fabric defined by quartz ribbons, kyanite grains and biotite flakes grown in the pressure shadows of the garnets. This fabric developed at the transition between granulite to amphibolite facies during the tectonic incision of granulites into gneisses. The EMP analyzes in 9 monazite grains provided relatively wide spectrum of ages with weighted average age of 392 ± 3.4 Ma (n = 53, MSWD = 1.33), staying within the error of the previous result. However, the age histogram suggests two separate events: at c. 400 Ma interpreted as initial monazite growth during HT-HP granulite facies metamorphism and at c. 386 Ma reflecting subsequent retrograde amphibolite facies overprint. These are in line with the isotopic data obtained by Kryza et al. (1996), O'Brien et al. (1997), Bröcker et al. (1998) and Budzyń et al. (2004).

The monazite in a coarse-grained, migmatitic gneiss (Qtz-Pl-Kfs-Bt-Grt-Ms) revealed complex internal structure from patchy zoning to less common concentric growth zoning. The inner zones in monazite are usually depleted in Y, whereas rims show elevated Y content, which suggests simultaneous growth of monazite and garnet followed by resorption reactions. The obtained dates are similar between zones and provide weighted average age of 379 ± 3.7 (n = 69, MSWD = 0.89) that may just record HT/MT-MP migmatization followed by fast cooling to lower temperatures. On the contrary, the monazite in a fine-grained, pelitic biotite gneiss (Qtz-Bt-Pl-Grt-Sil) yielded weighted average age of 390 ± 4.2 Ma (n = 44, MSWD = 1.26), similar to the identified waning stage of HP metamorphism in granulites but older than the c. 380 Ma intense migmatization in layered gneisses. Such monazite record indicates that the pelitic gneiss underwent MP metamorphism concurrently with HP metamorphism in the granulites, thus earlier than previously thought (Gordon et al. 2005; Kryza, Fanning 2007). The monazite geochronology confirmed Devonian ages of tectonometamorphic events in the GSM. The HT-HP metamorphism in granulites at c. 400-390 Ma overlapped with c. 390 Ma HT/MT-MP metamorphism in pelitic gneisses, the former rocks being metamorphosed 15-20 km deeper in the lithosphere. The obtained results, combined with structural observations, suggest that the exhumation of granulites and tectonic emplacement into gneisses commenced at ~390 Ma and was followed by the retrograde amphibolite facies overprint from ~386 Ma onwards, whereas gneisses, higher at the crust, yielded coevally to progressive metamorphism, migmatization and exhumation that terminated around 360 Ma. No data was found to support a wholesale HT-HP granulite event in gneisses of the GSM.

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Diamond-bearing gneisses in the Seve Nappe Complex, Scandinavian Caledonides – what is known about their P-T-t evolution?

Iwona KLONOWSKA[1], Marian JANÁK[2], Jarosław MAJKA[1,3], Igor PETRÍK[2], Nikolaus FROITZHEIM[4], David G. GEE[1], Vlasta SASINKOVÁ[5]

[1]*Department of Earth Sciences, Uppsala University, Villavägen 16, 752-36 Uppsala, Sweden; email: iwona.klonowska@geo.uu.se*
[2]*Earth Science Institute, Slovak Academy of Sciences, Dúbravská 9, PO Box 106, 840 05 Bratislava, Slovak Republic*
[3]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Al. Mickiewicza 30, 30-059 Kraków, Poland*
[4]*University of Bonn, Steinmann-Institut, Poppelsdorfer Schloss, D-53115 Bonn, Germany*
[5]*Institute of Chemistry, Slovak Academy of Sciences, Dúbravská 9, 840 05 Bratislava, Slovak Republic*

Metamorphic diamonds within the Seve Nappe Complex of the Scandinavian Caledonides provide evidence for ultra-high pressure metamorphism (UHPM) of the far travelled allochthonous units. Seve microdiamonds confirmed heretofore in two localities, Tväråklumparna and Åreskutan Mts (Majka et al. 2014; Klonowska et al. 2015), occur within gneisses which were migmatized to a different degree. Thermodynamic modelling shows that the peak-pressure conditions of the Åreskutan gneiss were reached at 4.1-4.2 GPa and 830-840ºC whereas the granulite facies overprint at 1.0-1.1 GPa and 850-860ºC. Ti-in-quartz thermometry applied to matrix-located quartz gives temperature of ~875ºC. Partial melting occurred below 2.0 GPa. Monazite Th-U-Pb chemical dating of the Tväråklumparna and Åreskutan gneisses shows that granulite facies metamorphism took place between 445 and 435 Ma. These ages correlate well with U-Pb zircon and titanite ages of the Åreskutan migmatites (ca 442-440 Ma; Claesson 1982; Williams, Claesson 1987; Gromet et al. 1996; Ladenberger et al. 2014). None of the geochronological methods applied so far to diamond-bearing Seve gneisses provided direct information about the age of the UHPM. Context-sensitive monazite dating by Majka et al. (2012) yielded ages of 455 Ma for low Y and relatively low Th monazite cores that have been interpreted as representing subsolidus conditions, probably close to the peak pressure of metamorphism.

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Formational analysis of volcanites of Alpine belt of Eastern Europe

Nataliia KOSTENKO[1]

[1] *Institute of Geology, Taras Shevchenko National University of Kyiv; Vasylkivska Str., 90; 02022 Kyiv, Ukraine;e-mail: knv@univ.kiev.ua*

The aim of this investigation is to define main regularities of volcanites development on studying all available petrographic diversity with statistical approach usage. The oxide and elemental composition of the main types of rocks (basalt, andesite, andesite, dacite, rhyolite) was processed by the cluster and factor analysis (R-method). To obtain the correct results is sufficient to have 4-6 representative sample analysis. The rocks within the positive values of the correlation coefficients designated two isolated groups (A and B; Fig. 1, 2). Their vectors are oriented at a slight angle to each other. It is obvious that marked petrochemical peculiarities of rocks indicate their origin in different geodynamic conditions: mantle petrogenesis for basalts and crust-mantle for andesibasalts and andesites.

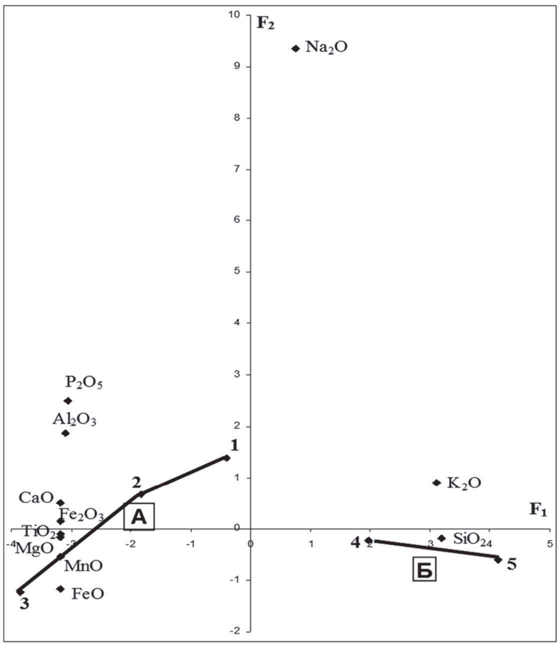

Fig. 1. Factor chart of the oxide composition of the main types of rocks of the Alpine belt of Eastern Europe. Species: 1 – basalts, 2 – andesibasalts, 3 – andesites, 4 – dacite, 5 – rhyolites. A, B – the trends of the rocks compositions, marked by the results of clustering within the positive values of the correlation coefficients.

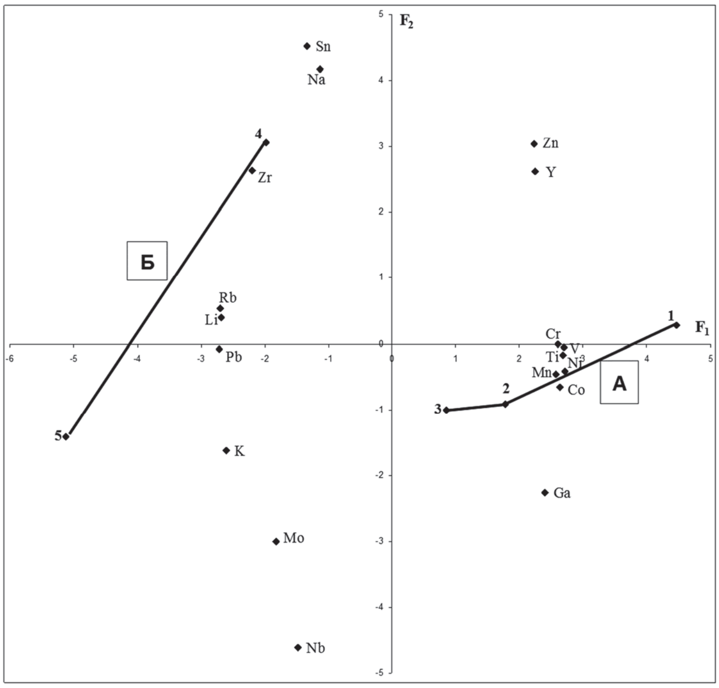

Fig. 2. Factor chart of elemental composition of the main types of rocks of the Alpine belt of Eastern Europe. Symbols – see on Fig. 1.

Observed gap in composition of explored rocks indicates the interrupted character of petrochemical evolution of basic-intermediate and acid volcanic buildups and therefore of absence of direct genetic connection between them. Based on numerical geological formation analysis of Neogene-Quarternary volcanites of Alpine fold-thrust belt of Eastern Europe are supposed to determine 2 formation types: basalt-andesibasalt-andesites (basalt-andesites) and dacites-rhyolites.

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From accretion to collision: high pressure/low temperature metamorphism and timing of the Kaczawa Metamorphic Complex, NE Sudetes, Poland

Ryszard KRYZA[1], Arne P. WILLNER[2,3], Johannes GLODNY[4], Joanna KOSTYLEW[1], Hans-Joachim MASSONNE[3], Hans-Peter SCHERTL[2], Sarah SHERLOCK[5]

[1]*Department of Geological Sciences, University of Wroclaw, ul .Cybulskiego 30, 50-205 Wroclaw, Poland,*
[2]*Institut für Geologie, Mineralogie und Geophysik, Ruhr-Universität, 44780 Bochum, Germany, arne.willner@rub.de, hans-peter.schertl@rub.de*
[3]*Institut für Mineralogie und Kristallchemie, Universität Stuttgart, Azenbergstr.18, 70174 Stuttgart, Germany, h-j.massonne@imi.uni-stuttgart.de*
[4]*Deutsches GeoForschungsZentrum, Telegrafenberg, Haus B, 14473 Potsdam, Germany, johannes.glodny@gfz-potsdam.de*
[5]*Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, England, sarah.sherlock@open.ac.uk*

The Kaczawa Metamorphic Complex (KMC) is an isolated block in the northeastern Polish Sudetes between the Intrasudetic and the Sudetic Marginal Fault zones. It comprises two different rock units: (1) a tectonically disrupted, but complete metasedimentary-metavolcanic succession of Cambrian to Devonian age on a Cadomian basement and (2) a series of local mélange bodies containing blocks of diverse metamorphic rocks in a slaty matrix of Upper Devonian to Early Carboniferous redepositional age. Main internal deformation is a top-to-NW thrusting.

Metamorphism is characterized by occurrence of epidote blueschist in all units of the KMC and local jadeite-bearing metatrachyte. Blue amphibole varies from glaucophane and Fe-glaucophane to riebeckite composition. Na-amphiboles are rimmed by Na-Ca-amphiboles and Ca-amphiboles. White mica is phengite with maximum Si-contents varying between 3.5-3.6 apfu in blueschist and metatrachyte and 3.3-3.4 apfu in metasedimentary rocks, depending on the samples studied. Peak metamorphic conditions were mainly estimated in blueschists and metatrachyte by calculating PT pseudosections, whereas most metasediments yielded minimum pressures only. Peak metamorphic conditions vary at 290-340°C, 6.5-9.5 kbar. The PT path is clockwise with slight heating during decompression, i.e. a temperature peak at lower pressure than the pressure peak. This results in a strong greenschist facies overprint of the chlorite to lower biotite zone.

We dated white mica in seven metasedimentary samples spread over the entire KMC using Ar^{40}/Ar^{39} laser ablation techniques yielding *in situ* spot ages. Age maxima vary continuously between 403±7 Ma and 303±7 Ma. Additionally, four Rb/Sr mineral isochrones of white mica bearing metasedimentary rocks yielded ages in the range of 338±3 to 323±5 Ma partly consistent with locally derived Ar^{40}/Ar^{39} ages. We interpret the ages as (1) due to accretion and related high pressure metamorphism particularly in the age range 403±7 Ma to 368±6 Ma and (2) resetting by later deformation related to a Carboniferous collision event and/or associated strike slip movements particularly in the age range 348±3 Ma to 303±7 Ma.

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Titanite – (Fe,Ti)-oxide association from the High Tatra granite as a marker of magma mixing under changing oxygen fugacity

Magdalena LAWENDOWSKA[1], Aleksandra GAWĘDA[1], Krzysztof SZOPA[1]

[1]*Faculty of Earth Sciences, University of Silesia, Będzińska St. 60; 41-200 Sosnowiec; m.lawendowska@gmail.com*

Introduction

Titanite and (Fe,Ti)-oxides are common accessories in I- and S-type granites. The High Tatra granite represents the mixed I/S type, with common attributes of interaction of the mafic and felsic sources and can be used to trace the inter-relations of (Fe,Ti)-rich accessory minerals.

Phase relations of titanite and (Fe,Ti)-oxides

In the mafic microgranular enclaves (MME) and schlieren the complex aggregates of titanite (Ttn), magnetite (Mt), ilmenite (Ilm) and rutile (Rt) was noted. Titanite was a product of biotite decomposition (Broska, Petrik 2011). Magnetite and ilmenite (Ilm_1) intergrowths are probably product of ulvöspinel break-up in the temperature range of 450-550°C. The spatial relations suggest co-crystallization of titanite and primary ulvöspinel. The whole polycrystalline aggregates are overgrown by ilmenite and rutile as the most external rim.

The complex $Mt+Ilm_1+Ttn+Ilm_2+Rt$ aggregates are through to result from the interaction of magmas showing different oxygen fugacity. Crystallization of late-magmatic titanite was connected to de-anorthitization of plagioclase what liberated Ca and Ti-rich biotite decomposition under increasing oxygen fugacity (Broska et al. 2007). The petrographical observations suggest that process was roughly contemporaneous with ulvöspinel decomposition and $Mt+Ilm_1$ intergrowths formation. Late ilmenite (Ilm_2) overgrowths on titanite mark the drop in oxygen fugacity, while the most external rutile rim represents the influx of late-magmatic oxidized fluid, according to a reaction: $4\ FeTiO_3 + O_2 = 4\ TiO_2 + 2\ Fe_2O_3$ (Broska, Petrik 2011). As hematite veinlets are commonly cutting the host granite this subsolidus reaction is possible, however was not completed.

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Peculiar Ba- and Ti-rich dark mica from the UHP metasedimentary rocks of the Seve Nappe Complex, Scandinavian Caledonides

Jarosław MAJKA[1,2], Łukasz KRUSZEWSKI[3], Åke ROSÉN[4], Iwona KLONOWSKA[1]

[1]*Uppsala University, Department of Earth Sciences, Villavägen 16, SE – 752 36 Uppsala, Sweden; e-mail: jaroslaw.majka@geo.uu.se*
[2]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków, Poland*
[3]*Polish Academy of Sciences, Institute of Geological Sciences, ul. Twarda 51/55, 00-818 Warszawa, Poland*
[4]*University of Bern, Institute of Geological Sciences, Baltzerstrasse 1+3, CH-3012 Bern, Switzerland*

Unusual in composition, Ba- and Ti-enriched dark mica was discovered in metasediments of the Seve Nappe Complex of the Scandinavian Caledonides occurring in the western Jämtland county of Sweden. These rocks were subjected to ultrahigh pressure metamorphism and overprinted by the medium pressure granulite facies event. The dark mica forms euhedral laths in a quartz and feldspar dominated matrix. The average contents of BaO and TiO_2 in this mica equal 11.54 and 7.80 wt%, respectively. The mean calculated crystallochemical formula is as follows: $(K_{0.54}Ba_{0.39}Na_{0.02}Ca_{0.01})\Sigma_{0.96}$ $(Fe_{1.37}Mg_{0.85}Ti_{0.50}Al_{0.29}Mn_{0.01}Cr_{0.01})\Sigma_{3.03}(Si_{2.59}Al_{1.41})\Sigma_{4.00}O_{10}(OH_{1.30}O_{0.66}F_{0.02}S_{0.01})\Sigma_{1.99.}$ Oxyannite, oxy-ferrokinoshitalite and siderophyllite are dominating end-members. The petrographical observations suggest that the dark mica must have been formed at a late stage in the parental rock evolution during the granulite facies event.

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Detrital opaque minerals from magnetic fraction of modern Arafura Sea sediments, eastern Indonesia: a preliminary report

Beata MARCINIAK-MALISZEWSKA[1], Krzysztof MALISZEWSKI[1], Anna MACIOCH[1]

[1] *Institute of Geochemistry, Mineralogy and Petrology, Faculty of Geology, University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland, e-mail: beata.marciniak@student.uw.edu.pl*

Samples of bottom sea sediments were collected along SW shoreline of New Guinea island in eastern Indonesia. They are fine-grained and mostly represented by muddy sand or sand. The magnetic fraction was separated by means of Frantz magnetic separator (0.5A current) from 63-250 µm grain-size class.

Detailed petrographic observations, including grain counting, and SEM studies were performed to distinguish compositional and textural features of detrital opaque minerals of the magnetic fraction. The group is very manifold and consists primary of magnetite, hematite, ilmenite and Cr-spinel with several types of textures. As homogenous and mostly monocrystalline grains occur magnetite (type I), ilmenite (type II) and Cr-spinel (type III). Nonhomogenous grains are represented by magnetite-ilmenite (type IV, V) and magnetite-hematite (type VI, VII) intergrowths with trellis or composite textures. Lamellae of ilmenite or hematite in type IV and VI are parallel to {111} of the host magnetite, but composite grains representing type V and VII show no distinct orientation along any structural planes. Moreover, hematite forms polycrystalline grains with two types of textures corresponding to martite (type VIII) and blocky hematite (type IX), often with Ti-rich exsolutions.

Electron probe microanalyses were carried out on mineral grains representing the most common forms in several samples. Among homogenous magnetite grains (type I) one can distinguish two groups: Ti-poor and Ti-rich. The first assemblage contains also lower amounts of Fe^{2+}, Mg, Mn, Al, and higher Fe^{3+}, which is similar to chemical composition of host magnetite with ilmenite (type IV, V) or irregular hematite intergrowths (type VII). Magnetite with trellis hematite (type VI) stands out with slightly higher amounts of Mg and Al, while the range of Ti content is similar to type I-magnetite. All studied forms of magnetite have similar amounts of Cr and V. Homogenous ilmenite grains (type II) also show differences in Ti content: Ti-rich group is characterized by lower amount of Mg, Al, Fe^{3+} and enrichment in Mn and Fe^{2+}, which is analogous to composition of guest ilmenite from type IV and V. However, ilmenite from nonhomogenous grains (type IV, V) can be distinguished by the highest content of Mn. Hematite forming irregular intergrowths with magnetite (type VII) is almost pure Fe_2O_3, unlike the other hematite assemblages with higher amounts of Mg, Mn, Fe^{2+}, Al and Ti. The most distinct is high Fe^{2+} and Ti content in hematite lamellae from type VI. Spinel assemblage representing type III shows very wide range of Cr, Mg, Al and Fe^{2+} amounts with dominating role of Cr and occasional presence of Fe^{3+}.

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Allanite-(Ce) and other epidote-group minerals from the Karkonosze pluton

Witold MATYSZCZAK[1], Andrzej KOZŁOWSKI[1]

[1]*Institute of Geochemistry, Mineralogy and Petrology, University of Warsaw, 02-089 Warsaw; e-mail: witold.matyszczak@uw.edu.pl; e-mail: a.j.kozlowski@uw.edu.pl*

Single crystals of epidote mineral group were obtained in Polish part of the Karkonosze pluton, in the vicinity of Karpniki, Karpacz, Podgórzyn, Michałowice and Szklarska Poręba. The collected specimens occurred both in porphyritic variety of granite and in pegmatites. They differ in size (from 11 to 0.1 mm) and in chemical composition. The latter evidenced clinozoisite and allanite-(Ce) as the main species. Epidote occurs only incidentally as rims in zoned crystals. Crystals occurring in granite, contrary to those from pegmatites, are oscillatory zoned but frequently zonation is hardly visible. Some grains reveal complicated multistage crystallization path with dissolution, crushing, healing and overgrowing by epidote in different formation episodes. For example a grain from the Michałowice quarry shows transition from partly dissolved clinozoisite in core trough allanite-(Ce), epidote and clinozoisite at the end (Fig. 1).

Allanite-(Ce) is rather seldom accessory mineral in Karkonosze pegmatites. It was found only in 3 on 11 investigated pegmatites bodies. They are frequently altered to patchy or perlitic textures and with cations deficit in the altered parts. It seems these are typical alteration textures caused by interaction with postmagmatic fluids. Allanite crystals from different localities in Karkonosze, both from granite and pegmatite, differ significantly in the REE patterns. Beside typical main components the presence in various grains of rare minor elements like P (up to 0.39 wt% P_2O_5), As (up to 0.19 wt% As_2O_5), B (up to 0.05 wt% B_2O_3), Be (4.36 wt% BeO) or V (up to 5.53 wt% V_2O_3) is worth notice.

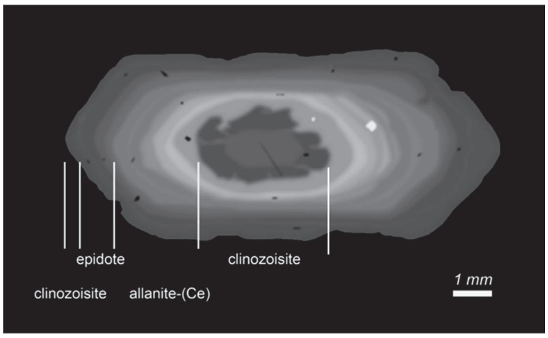

Fig1. BSE microphotograph of clinozoisite-allanite-(Ce) grain from the Michałowice quarry. Larger white spot – uraninite, the smaller one probably is hematite.

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Zircon evidence for recycling of subducted continental crust: Saxothuringian provenance of suspect terranes in the Central Sudetes, Bohemian Massif

Stanislaw MAZUR[1], Jacek SZCZEPAŃSKI[2], Krzysztof TURNIAK[2], Neal J. MCNAUGHTON[3]

[1]*Institute of Geological Sciences, Polish Academy of Sciences, Kraków Research Centre, Senacka 1, 31-002 Kraków, Poland; e-mail: ndmazur@cyf-kr.edu.pl*
[2]*Institute of Geological Sciences, University of Wrocław, 50-204 Wrocław, Pl. Borna 9, Poland; e-mail: jacek.szczepanski@uwr.edu.pl; krzysztof.turniak@uwr.edu.pl*
[3]*John de Laeter Centre for Mass Spectrometry, Curtin University, GPO Box U1987 Perth, Western Australia 6845*

The Central Sudetes comprise a mosaic of various presumably allochthonous tectonic units that are squeezed between the Saxothuringian and Brunian microplates in the west and east, respectively. A number of small suspect terranes were previously distinguished in the area (e.g., Cymerman et al. 1997; Aleksandrowski, Mazur 2002), based on different lithological inventories, contrasting metamorphic paths and widespread tectonic contacts. However, due to scarce stratigraphic evidence available and the lack of provenance studies it was virtually impossible to reconcile whether these terranes are exotic units assembled in an active margin setting (e.g., Johnston et al. 1994) or represent fragments of a single, dismembered accretionary wedge.

To provide new constraints on the provenance of the Central Sudetes, six zircon concentrates from the metasediments and metavolcanics of the Orlica-Śnieżnik dome and Kłodzko massif have been dated using SHRIMP II (Mazur et. al. 2012, 2015). Four metasedimentary samples yielded Precambrian age spectra similar to those that are characteristic of the Cadomian terranes: (1) Archean and Paleoproterozoic zircons scattered between 3380 and 1860 Ma, and (2) copious Neoproterozoic zircons dated at 800-560 Ma. Two of the analysed samples also comprise Early Cambrian and Early-Late Cambrian zircons. The estimated maximum sedimentation ages for the Młynowiec and Wyszki paragneisses are 563±6 Ma and 566±4 Ma, respectively. Younger maximum sedimentation ages were obtained for the Stronie mica schist (532±6 Ma) and for the Goszów quartzite (490±9 Ma). Consequently, the metasediments of the Orlica-Śnieżnik dome are interpreted as three distinct metasedimentary successions representing a Neoproterozoic back-arc basin, Early Cambrian incipient rift basin, and an uppermost Cambrian - Lower Ordovician post-rift succession, respectively.

Two metavolcanic samples were analysed along with the metasediments. The Kłodzko Fortress pyroclastic metarhyodacite gave an igneous emplacement age of 536±2 Ma equal within error with the maximum sedimentation age of the Stronie schist. The magmatic precursor to the subvolcanic Gniewoszów metarhyolite was dated at 501±3 Ma, the age that closely correlates with the emplacement of the Orlica-Śnieżnik gneisses.

The dated samples come from two suspect terranes – the Orlica-Śnieżnik dome and the Kłodzko massif in the Central Sudetes that are characterised by contrasting timing of metamorphism and exhumation. However, the results obtained show a similar provenance of the studied units and their common affinity to the Saxothuringian terrane. Since the Central Sudetes are separated from Saxothuringia by a collisional suture (Mazur, Aleksandrowski 2001; Jeřabek et al. 2016) the pre-Variscan basement must represent the deformed and metamorphosed, allochthonous equivalents to Saxothuringian lithologies. They were probably subducted together with the Saxothuringian passive margin during a Variscan collisional event and then exhumed within an accretionary wedge in front of the Brunia microcontinent.

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X-ray computed microtomography 3D modeling of garnets from the Międzygórze eclogite, Sudetes, Bohemian Massif

Maria MŁYNARSKA[1], Karolina KOŚMIŃSKA[1], Jacek TARASIUK[3], Sebastian WROŃSKI[3], Jarosław MAJKA[1,2], Iwona KLONOWSKA[2]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland; e-mail: mkmlynarska@gmail.com*
[2]*Department of Earth Sciences, Uppsala University, Villavägen 16, Uppsala SE-752-36, Sweden*
[3]*AGH – University of Science and Technology, Faculty of Physics and Applied Computer Science, Mickiewicza 30, 30-059 Kraków, Poland*

High-resolution x-ray computed tomography (X-ray μCT) was used to get the micromorphology and spatial distribution of garnets in the Międzygórze eclogite. The modeling is an important complementation of the previous research (Majka et al. 2016), helping to track the growth mechanisms and crystallization sequence (e.g. Gaidies et al. 2015; Robyr et al. 2014).

Majka et al. (2016) concentrated on reinvestigation of questioned ultrahigh-pressure (UHP) origin of eclogites in the central Sudetes. Kyanite-bearing eclogite from the classical locality of the Orlica-Śnieżnik Dome was investigated by the available geothermobarometric and thermodynamic modeling techniques to estimate the pressure-temperature (P-T) conditions under which it was formed. The calculated P-T are c. 28-30 kbar and 770-830°C. Garnet forms anhedral to subhedral porphyroblasts occurring in the omphacite-quartz dominated matrix. Compositional step profiles give an impression of normal core to rim zoning with slightly decreasing almandine and increasing pyrope. Grossular is rather stable or reveals multiple core domains which are separated by local pyrope highs and grossular lows. These multiple cores and rims are considered to have been formed via coalescence of several smaller grains.

Already done, preliminary μCT model of investigated sample, has shown that many garnets grew one on another. Nearly no single crystal is separated from the others. The model reveals a comprehensive view of the eclogite sample, which contains many different peculiar forms of garnets like: cones, hourglasses or mushrooms made up of a few crystals. Hence this μCT approach confirms that garnets in the Międzygórze eclogite formed via coalescence process, which resulted in a complex chemical zoning pattern.

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The Leszczyniec Unit in the eastern Karkonosze-Izera Massif revisited

Maria MŁYNARSKA[1], Stanislaw MAZUR[2], Jarosław MAJKA[3,1]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland; e-mail: mkmlynarska@gmail.com*
[2]*Institute of Geological Sciences, Polish Academy of Sciences, Senacka 1, 31-002 Kraków, Poland*
[3]*Department of Earth Sciences, Uppsala University, Villavägen 16, Uppsala SE-752-36, Sweden*

The present configuration of metamorphic units in the West Sudetes has been attributed to nappe tectonics recognized on the basis of structural, metamorphic, geochemical and geochronological data (Mazur, Kryza 1996; Mazur, Aleksandrowski 2001). The original nappe scheme was recently revised by Žáčková et al. (2010), who distinguished four major tectonic units. The parautochthonous unit consists of the Neoproterozoic to Upper Cambrian/Lower Ordovician orthogneisses (Kröner et al. 1994; Tichomirowa et al. 2001) of the Lusatian and Karkonosze-Izera Massifs. The lower thrust sheet crops out structurally above the Izera orthogneiss in the SE part of the Karkonosze-Izera Massif and contains mostly garnet-bearing micaschists with intercalations of orthogneisses, quartzites, calcsilicate rocks and marbles. A petrological study of garnet-bearing micaschists provided evidence of blueschist-facies metamorphism (18-19 kbar and 460-520°C; Žáčková et al. 2010). The middle thrust sheet includes garnet-free micaschists, phyllites and marbles with a high content of metavolcanic rocks. The metabasites of this unit experienced blueschist-facies metamorphism (e.g., Kryza, Mazur 1995). The uppermost thrust sheet is the Leszczyniec Unit composed of medium-pressure metabasites and trondhjemitic gneisses (Kryza, Mazur 1995) of the late Cambrian age (Oliver et al. 1993).

The nappe structure of the Karkonosze-Izera Massif 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 interpreted as a northern prolongation of the Teplá-Barrandian domain (Mazur, Aleksandrowski 2001; Jeřábek et al. 2016). In that context, the uppermost thrust sheet, the medium-pressure Leszczyniec Unit, was interpreted as an accreted fragment of the Saxothuringian oceanic crust (Mazur, Aleksandrowski 2001). Alternatively, the Leszczyniec Unit may have been derived from mafic lower crust of the Teplá-Barrandian upper plate as it consists of felsic rocks and metagabbro of the latest Cambrian age (Oliver et al. 1993) corresponding to a time of widespread Cambro-Ordovician continental rifting before the opening of the Saxothuringian/Rheic Ocean.

Our upcoming study is aimed at solving this dilemma using structural, petrological, geochemical and geochronological methods. We are going to find out whether the Leszczyniec Unit indeed represents a vestige of the Saxothuringian Ocean that dates back to the late Cambrian-Early Ordovician time. In the reverse case, the Leszczyniec rocks would be the first documented occurrence of Teplá-Barrandian upper plate that is hypothesized to be mostly hidden in the Sudetes beneath the Intra-Sudetic Basin. Metamorphic ages from the Leszczyniec Unit will provide the best clue for the commencement of collision between the Saxothuringian and Teplá-Barrandian terranes.

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Preliminary results of dating of detrital zircons from the youngest loess in Poland

Jerzy NAWROCKI[1], Magdalena PAŃCZYK[1]

[1]*Polish Geological Institute – Polish Research Institute, 4, Rakowiecka Street, 00-975 Warszawa; e-mail: Magdalena.Panczyk@pgi.gov.pl;*

Loess deposits in the western Ukraine and southern Poland form the westernmost part of a widely distributed loess cover named the 'East European Loess Province'. In the Lublin, Volhynia and Podole Uplands, loess sediments were deposited mostly during later periods of the Pleistocene (ca. 25-15 ka). The loess sources and directions of aeolian transport have been defined on the basis of mineralogical studies or were documented by the anisotropy of magnetic susceptibility (e.g. Chlebowski et al. 2003; Nawrocki et al. 2006) in the context of palaeogeography. The main aim of this study was dating zircon grains separated from youngest loess from SE Poland for their detailed provenance.

Samples of loess for zircon separation were taken from six loess outcrops located in different parts of SE Poland: Humniska (Carpathian orogen), Radymno (20 km NW of the Carpathian Overthrust), Nieledew and Obrowiec (east of Lublin), Wąchock and Zlota (west of Vistula River). The isotope analyses of selected zircon grains were processed on the SHRIMP IIe/mc device in the Micro-area Laboratory of Polish Geological Institute – NRI.

Single-grain U-Pb dating of zircon grains separated from studied loess have given predominantly Cadomian, Caledonian and Variscan ages. Paleoproterozoic zircons are less frequent and they could be supplied to the local sedimentary basins during earlier stages of erosion of the East European Craton in the Paleozoic and Mesozoic.

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Toward accurate xenotime chemical ages – the data selection for low-Pb compositions.

Michał OCHOTNY[1], Krzysztof TURNIAK[1], Grzegorz ZIELIŃSKI[2]

[1]*Institute of Geological Sciences, University of Wrocław, 50-204 Wrocław, Pl. Borna 9, Poland: krzysztof.turniak@uwr.edu.pl*
[2]*Polish Geological Institute – Polish Research Institute, 4 Rakowiecka Street, 00-975 Warszawa; e-mail:grzegorz.zielinski@pgi.gov.pl*

Xenotime is one of the most challenging minerals used in chemical dating due to its low uranium, thorium and lead concentrations. To evaluate the influence of lead contents measured by electron microprobe on the calculated mean age of xenotime we re-examined the xenotime from two-mica granite (Siedlimowice quarry, Strzegom-Sobótka massif, SW Poland), dated previously at 306.4 ± 0.8 Ma (U-Pb, ID-TIMS; Turniak, Bröcker 2002).

The chemical composition of eight grains (33 analytical points) was investigated using a Cameca SX100 instrument with an accelerating voltage of 15kV and beam current of 200 nA. The X-ray lines used were UMβ, ThMα and PbMβ and the counting time was 240 s. The measurements were ZAF-corrected for matrix measured independently with 40nA beam current. Appriopriate corrections for X-ray line interferences were done.

The xenotime forms transparent greenish bypiramidal crystals up to ca 150 µm with oscillatory zoning and common monazite and zircon inclusions. It contains 31.5-35.2 wt% Y, 0.1-1.4 wt% Th and 0.5-2.5 wt% U. The chondrite-normalized REE patterns are typical for magmatic xenotime, showing negative Eu anomaly, depletion in LREE and enrichment in HREE with generally flat pattern from Gd to Yb.

The age calculations show a distinct positive correlation between the calculated single ages and lead contents for compositions below 0.05 wt% Pb. This effect can be attributed to the overestimated background level. This results in the underestimated values of measured Pb, especially evident in the analyses with lowest Pb contents, because of low signal-to-background ratio. With growing Pb concentration the influence of background overestimation becomes smaller. The consistence of the calculated age datapoints, poor at low Pb contents, increases considerably above 0.09 wt% Pb, the treshold ten times higher than the detection limit for Pb in the analytical session.

The Pb-underestimated compositions deviate the slope of regression line on the Pb versus Th* diagram shifting the intercept below 0 on Pb axis. It results in the incorrect age at 338±18Ma (33 analyses; 2σ; MSWD=0.3; CHIME method after Suzuki et al. 1991 and Suzuki & Adachi 1991), inconsitent with the 287±6Ma (33 points; 2σ) mean age obtained according to Montel et al. (1996) calculation scheme. Five analyses with Pb content above 0.09 wt% Pb give the mean age 304±10 Ma (2σ; after Montel et al. 1996) that is similar to the reference value obtained earlier by Turniak and Bröcker (2002).

Our results show that meaningful mean chemical age of xenotime can be obtained from a dataset limited to high-in-Pb analyses showing flat and consistent distribution on the Pb versus chemical single age diagram.

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REE-bearing minerals from rapakivi-type granites from Pietkowo IG1 borehole (East European Craton, NE Poland)

Magdalena PAŃCZYK[1], Jakub BAZARNIK[1], Grzegorz ZIELIŃSKI[1], Leszek GIRO[1]

[1]*Polish Geological Institute – Polish Research Institute, 4, Rakowiecka Street, 00-975 Warszawa; e-mail: Magdalena.Panczyk@pgi.gov.pl; Jakub.Bazarnik@pgi.gov.pl*

The rapakivi-type granites *in situ* in Poland are known only from the deep boreholes. They are located in NE Poland within the south-eastern part of East European Craton – Mazowsze Domain (Bagiński et al. 2001). The age of zircons from granitoids was estimated to be 1818±15 Ma (Krzemińska et al. 2007).

The samples of rapakivi granites from the Pietkowo IG1 borehole were studied as a potential source for rare earth elements. The main aim of research was to compare the obtained results from the Pietkowo IG 1 borehole with the enriched intervals within sedimentary cover and much younger Tajno Complex as well as Ełk Massif. Moreover, the detailed analyses of REE-bearing minerals were also the matter of investigations.

The research methodology has had the following sequence: *in situ* chemical analyses of major and trace elements (including REE) in borehole samples with use of the handheld XRF Olympus Delta 50 Premium spectrometer (Pańczyk et al. 2015a) to obtain interesting and elevated intervals in drill core samples. The single-spot, small-area XRF-analyses were performed for each meter of drill core (from ca 930 m to ca 1340 m below ground level, ca 410 m total, 413 analytical points). After the designation prospective samples, the detailed micro-area studies on mineral paragenesis as well as chemical composition of minerals were performed using Cameca SX 100 electron microprobe analyzer.

The contents of La and Ce obtained with use of XRF spectrometer were chosen as indicators of the REE-bearing minerals occurrence in analyzed rocks. The maximum obtained values of La and Ce in Pietkowo borehole were 1882 ppm and 2849 ppm, respectively (average ca 118 ppm and ca 226 ppm, respectively) in comparison to, for example, Tajno IG4 La – 7193 ppm (average ca 177 ppm; Pańczyk et al. 2015b), and Ce – 5204 ppm (average ca 255 ppm), and Ełk IG4 La – 3241 ppm (average ca 167 ppm) and Ce – 4313 ppm (average ca 294 ppm; Pańczyk et al. 2015b).

The main rare earth elements mineral is allanite which forms large crystals accompanied with other REE-bearing minerals such as titanite, apatite, zircon, which are enriched in LREE. Very small amounts of REE were also found in magnetite.

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Physicochemical parameters of metasomatic alterations at the contact of a dacite stock with the red-bed Ashua Formation, Peru

Andrzej PAULO[1], Justyna CIESIELCZUK[2], Krzysztof GAIDZIK[2], Jerzy ŻABA[2]

[1]*AGH – University of Science and Technology, Mickiewicza 30, 30-059 Kraków Poland; e-mail: andrzej.paulo@interia.pl*
[2]*Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec Poland; e-mail: justyna.ciesielczuk@us.edu.pl; k.gaidzik@gmail.com; jerzy.zaba@us.edu.pl*

An interesting mineral assemblage has been identified in the contact zone of a dacite stock intruding the Late Cretaceous red-bed Ashua Formation in the Huambo district, south Peru. It is tentatively ascribed to metasomatic, thermal alteration. The intricate geometry of the contact, and parageneses, reflects mylonitization which accompanied and postdated intrusion, and led to roof pendants, permeable zones, etc. (Paulo et al. 2013).

Ashua outcrops were examined in the field up to a distance of 1-3 km from the contact with dacite. With the aim of distinguishing neosome parageneses from paleosome (sedimentary and diagenetic) and from the weathering overprint, research was undertaken using polarizing microscopy (transmitted and opaque), SEM-EDS, EMPA and X-ray methods. Recognition of the metasomatic assemblage enabled plotting of the studied rocks on the appropriate IUGS diagram and adequate temperature- and pH intervals of the alterations to be determined (Zharikov et al. 2007).

A rather simple dacite mineralogy (albitised intermediate plagioclases, quartz, pargasite hornblende, phlogopite, rare acmite augite) contrasts with the broad scope of minerals in the hosting siliciclastic-carbonate-evaporitic sequence. The alteration zone is characterized by the presence of diopside, epidote (pistacite), alkali amphiboles (actinolite-tremolite, Mg-riebeckite, K-richterite and others), talc, and up to 11 species of zeolite and, occasionally, dravite. Undoubtedly, more minerals, e.g., feldspars, a plethora of clays, calcite, dolomite, gypsum, barite, celestite and analcime are present, but these are encountered in non-altered rocks as well.

The neosome assemblage falls in the fields of skarn, alkali-amphibole and aceite metasomatites, and propylites. Estimated temperatures of formation range from 500°C to 150°C and pH is ca 8. The main cations involved are Na, K, Mg and Ca.

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Bioavailability of Ni, Cr and Co in Polish ultramafic sites: from the parent rock through the soil up to the plants

Artur PĘDZIWIATR[1], Jakub KIERCZAK[1] , Jarosław WAROSZEWSKI[2]

[1]*University of Wrocław, Institute of Geological Sciences, 30 Cybulskiego St., 50-205 Wrocław, Poland, artur.pedziwiatr@uwr.edu.pl, jakub.kierczak@uwr.edu.pl*
[2]*Wrocław University of Environmental and Life Sciences, Department of Soil Sciences and Environmental protection, 25/27 C.K. Norwida St., 50-375 Wrocław, Poland, jaroslaw.waroszewski@up.wroc.pl*

Serpentine soils developed on peridotites and serpentinites are characterized by elevated concentrations of Ni, Cr and Co, compared to concentrations in Earth crust, and relatively high concentrations of Mg with low Ca, K and P. These characteristics of serpentine soils are responsible for their low productivity. On the other hand, plant growth on serpentine areas led to adaptation of species to unfavorable conditions of these soils. In this study we analyze bioavailability of Ni, Cr and Co in Polish serpentine soils using chemical extractions and direct measurements.

The studied soils are shallow, well drained, and developed over serpentinized peridotite (site 1 – Szklary Massif) and over serpentinite (site 2 – Jordanów). Serpentinized peridotite contains higher concentrations of Ni and Cr (2232 ppm and 2730 ppm, respectively) compared to serpentinite (1577 ppm and 2196 ppm, respectively). Cobalt concentrations do not exceed 100 ppm in both parent rocks. Nickel concentrations increase downwards within the profile in both sites, up to 2341 ppm in the ABw horizon in site 1 and 3944 ppm in the BwC horizon in site 2. The highest concentrations of Cr in site 1 are found in the A horizon (3503 ppm), while in site 2 they are found in the BwC horizon (2751 ppm). Cobalt concentrations do not exceed 170 ppm in both of the studied soil profiles. Furthermore, EDTA and DTPA-$CaCl_2$ extractions allow us to determine the available fraction of metallic elements. Chemical extractions demonstrate that availabilities of Ni and Co are higher in site 1 (up to 14%, A horizon; up to 16%, ABw horizon, respectively) compared to site 2 where proportion of available Ni is up to 5.3% in ABw horizon and Co up to 3.8% in the same horizon. Cr-availability in both soils does not exceed 0.5%. The DTPA-$CaCl_2$ extraction confirms higher availability of Ni in soil from site 1 compared to site 2. In contrast to the expected results of chemical extractions, plant species from site 2 contain higher concentrations of metallic elements despite higher availability of Ni and Co in site 1. Our results demonstrate that plants accumulate metallic elements from available soil fractions to only some extent. We suggest that accumulation of metallic elements is governed by the presence of Ca and/or Mg bearing minerals (i.e. tremolite, olivine) in the parent rocks. Weathering of these minerals leads to the release of Ca and Mg that cope with metallic elements in plasma membrane of roots. Furthermore, some other factors (i.e. pH, presence of allogenic material, genetic diversity within plant population) affect the bioavailability of metallic elements and accumulation by plants.

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Before it gets subducted: a zircon perspective on incompatible element distribution in oceanic crust (ODP Site 735B, Atlantis Bank)

Anna PIETRANIK[1]

[1]*Department of Experimental Petrology, University of Wroclaw , pl. Uniwersytecki 1, 50-137 Wrocław; e-mail: anna.pietranik@uwr.edu.pl*

Plagiogranites form only 0.5% of the oceanic crust section drilled in ODP Site 735B, but as late melts they carry an important budget of incompatible elements. Also, they are distributed throughout the whole section. Therefore, plagiogranites offer insight into late magmatic/high temperature hydrothermal processes within the oceanic crust. Such processes may be responsible for mobility and redistribution of many incompatible elements, which later may affect how these elements are further mobilized during serpenitization, as well as melting and dehydratation in subduction settings.

Most of the major mineral assemblages in plagiogranite veins is altered or metamorphosed (Robinson et al. 2002) and it is difficult to reconstruct magmatic stage of plagiogranite crystallization based on major minerals or whole rock geochemistry. Therefore, zircon may be the only phase that records magmatic evolution of these felsic veins and offers insight into late stages of oceanic crust development.

This study presents new zircon data including Hf and O isotopes and major and trace elements from four depth sections in the slow spreading oceanic crust (ODP Site 735B, Atlantis Bank, South-West Indian Ocean). The uppermost section comprises oxide gabbro, whereas deeper sections include numerous plagiogranite veins. Chemical and isotope composition of the zircon records two stages of felsic melts formation within the oceanic crust. In the first stage zircon crystallized in fractionated melts, the melts later migrated through the oceanic crust and currently are present at all depths, but dominate in the lower part of the ODP Site 735 B. The second stage was probably related to later shearing and deformation during crustal uplift and produced felsic melts by hydrous partial melting in the upper 500 m of the oceanic crust section.

Mobility of incompatible elements was particularly high in the first stage and extremely REE-enriched veins are currently common also in the uppermost part of the gabbroic section. Majority of the REE budget resides in apatite and zircon and stability of these phases will control the elements release in subsequent stages, for example during subduction.

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Tin sulphides from the eastern envelope of the Karkonosze granite: preliminary data.

Marta POLAK[1], Bożena GOŁĘBIOWSKA[1], Adam PIECZKA[1]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Department of Mineralogy, Petrography and Geochemistry, al. Mickiewicza 30, 30-059 Kraków, Poland, e-mail: mapolak@agh.edu.pl*

Stannite, stannoidite and mawsonite were recognized in two different assemblages in supergenic ore mineralization of Rudawy Janowickie range. The Sn sulphides are components of ores disseminated in amphibolites and mica schists in the Rędziny and Miedzianka areas within the eastern metamorphic envelope of the Karkonosze granite. Those small deposits contain polymetallic mineralization composed mainly of arsenopyrite, chalcopyrite, pyrrhotite, sphalerite, galena and many subordinated sulphides, Ag(Cu)-Pb-Bi(Sb) sulphosalts and cassiterite in the case of Rędziny (Pieczka et al. 2009), various Cu-sulphides, arsenopyrite, magnetite, sphalerite, tetrahedrite-tennantite and many other minerals in the Miedzianka area (Mochancka et al. 2012). In this paper we focused on Sn sulphides investigated on the micro scale with SEM and EMP-WDS methods.

The Sn sulphides are commonly represented by stannite, Cu_2FeSnS_4, stannoidite, $Cu_8Fe_3Sn_2S_{12}$ and mawsonite, $Cu_6Fe_2SnS_8$, and coexist mainly with chalcopyrite, sphalerite, arsenopyrite and various of Ag(Cu)-Pb-Bi(Sb) sulphosalts at Rędziny, whereas at Miedzianka they occur as inclusions in the chalcopyrite-bornite assemblages. In the Rędziny ores they were most often observed as very subtle emulsions and intergrowths with chalcopyrite in sphalerite grains. Microinclusions of stannite in sphalerite, up to 5 mm across, looked like "smeared paint". We noted also many greater stannite grains with cryptoinclusions of sphalerite, about or even below 1 µm in size. In contrast to Rędziny, individual, homogeneous grains of stannoidite (up 15 mm) were found at Miedzianka. The compositions of stannite, stannoidite and mawsonite are usually close to their stoichiometric formulae. However, in composition of stannite from Rędziny and inclusions of stannoidite from Miedzianka very high contents of Zn are noted, varying respectively in the ranges of 2.98-6.35 wt% and up to 8.66 wt%. Mawsonite from Miedzianka, coexisting with stannoidite, contains also an admixture of Zn (up to 3.6 wt%). On the other hand, the associated sphalerite shows increased contents of Fe and Cd, 4.75-5.7 wt% and 0.6-1.6 wt%, respectively. The compositions of the Sn sulphides show moreover traces amount of In, Mn, Ag, Pb and Co. Inclusions of the tin sulphides and chalcopyrite in sphalerite, are probably a result of the breakdown during cooling of a primary sphalerite, saturated in Fe, Cu and Sn, crystallized from hydrothermal solutions in a high-temperature episode. The temperature of its breakdown was estimated on the basis of the sphalerite-stannite geothermometer of Nakamura and Shima (1983) at 340–280^{o}C (Pieczka et al. 2009).

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Mantle roots of NE part of the Variscan Orogen in Europe: Provenance and geological history

Jacek PUZIEWICZ[1], Magdalena MATUSIAK-MAŁEK[1], Theodoros, NTAFLOS[2], Anna KUKUŁA[1], Mateusz ĆWIEK[1]

[1]*University of Wrocław, Institute of Geological Sciences, Pl. M. Borna 9, 50-204 Wrocław, Poland; e-mail: jacek.puziewicz@ing.uni.wroc.pl*
[2]*University of Vienna, Department of Lithospheric Research, Althanstrasse 14, Vienna, Austria*

The subcontinental lithospheric mantle (SCLM) beneath NE part of the Variscan Orogen in Europe (Lower Silesia in SW Poland and Upper Lusatia in SE Germany) consists mostly of harzburgites (Puziewicz et al. 2015). The subordinate clinopyroxene occurring in these rocks, despite primary textural appearance, is a late addition to protoliths which are residues after extensive (up to 30%) partial melting. The mineral was introduced into the harzburgites by alkaline basaltic melts and their alkaline-carbonatitic predecessors, which migrated upwards from asthenospheric sources during rifting in the Variscan foreland of the Alpine-Carpathian chain in Cenozoic. Thus, the pre-rifting history of the SCLM beneath the region must be deciphered from olivine and orthopyroxene.

The content of forsterite in olivine divides the Lower Silesian/Upper Lusatian harzburgites into two groups: A (olivine Fo 90.5-92.0), and B (olivine Fo 84.0-90.0; Puziewicz et al. 2015). The Al content in orthopyroxene from A harzburgites is typically 0.05-0.10 atoms of Al per formula unit, corresponding to 0.5-2.5 wt.% Al_2O_3. Part of the B harzburgites contains orthopyroxene of similarly low Al content, which is not correlated with composition of coexisting olivine. Some of the B harzburgites contain orthopyroxene which is richer in Al (up to 0.24 atoms of Al pfu, corresponding to ca 5.7 wt.% Al_2O_3), which content is negatively correlated with that of forsterite in olivine.

The Al-poor orthopyroxene, similar to from the the Lower Silesian European mantle domain, is occurring in (1) oceanic mantle formed in the mid ocean ridges (MOR) and (2) mantle wedge affected by extreme melting in the supra-subduction zones (SSZ). Orthopyroxene from the MOR harzburgites contains 2.0-6.0 wt.% Al_2O_3, whereas that from SSZ is poorer in Al (< 2.0 wt.% Al_2O_3; Bonatti, Michael 1989). Thus, we infer that the Lower Silesian SCLM originated rather in the MOR setting.

The B harzburgites were formed by reactive basaltic melt percolation, which lowered the forsterite content in olivine and Mg# in orthopyroxene ("Fe metasomatism"). The harzburgites containing Al poor orthopyroxene supposedly originated due to percolation of tholeiitic basaltic melts in MOR environment, which leads to production of low-Al orthopyroxene (e.g. in the peridotites from East Pacific Rise; Dick, Natland 1996. Textural relationships show that the Al-enriched B harzburgites were also affected by "Fe metasomatism", but by alkaline basaltic melt percolating in SCLM during Cenozoic rifting.

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Aerobic and anaerobic microbial degradation of *n*-alkanes from the sandstones in hydrocarbon seeps area

Agnieszka ROŻEK[1], Oliwia GRAFKA[1]

[1]*Institute of Geochemistry, Mineralogy and Petrology, Faculty of Geology, University of Warsaw; e-mails: a.rozek@uw.edu.pl; oliwia.grafka@uw.edu.pl*

One of the most important alteration processes of petroleum compounds is the biodegradation by the subsurface microbial communities, predominantly bacteria and archaea. Compositional modification of crude oils by microorganisms may occur during migration and within reservoirs, in porous sediments such as sandstone and limestone. An investigation of the effect of microbial activity on the molecular composition of organic matter (OM) is an important aspect in the organic geochemistry researches.

The results of this geomicrobiological and geochemical study show the direct microbial degradation of petroleum hydrocarbons extracted from the sandstone samples in natural hydrocarbon seeps area in the Flysch Carpathians of south-eastern Poland. The aerobic and anaerobic microorganisms, isolated from the weathering zone of sandstone, could utilize sandstone's organic matter as the sole carbon and energy source. Isolated microorganisms, including autotrophic and heterotrophic organisms were incubated using the mineral Starkey medium with application of rock samples as the source of microorganisms.

The presented results are focused on aliphatic fraction (*n*-alkanes, the maximum number of carbon atoms in the chain was 34). The extract from the bedrock is dominated by short chain *n*-alkanes, with an even number of atoms. In the rock sample after microbiological experiment a significant decrease in the distribution of long-chain compounds was noticed. The highest degree of biodegradation was observed in the anaerobic cultures, in which concerned both long- and short-chain alkanes were degradated. The most interesting results concern aerobic cultures. As a result of biotic processes nearly all long chain *n*-alkanes were removed. Simultaneously, the increase of *n*-alkanes with a chain length n-C_{14} – n-C_{24} was noted. In the abiotic control there were no significant changes in the distribution of *n*-alkanes.

The results of this study confirm that isolated microorganisms play an important role in the biotransformation of organic matter extracted from the sandstones in hydrocarbon seeps area. The results show that the biodegradation under aerobic and anaerobic conditions proceeds via different biological mechanisms. Given the reports in the literature these results seem to be very interesting. These data confirm that the preferences of aerobic microorganisms may involve the use of long-chain compounds as an electron donor. An enrichment of aerobic samples in short-chain hydrocarbons probably indicates microbiological activity whereby there has been a breakdown of long-chain compounds of the shorter fragments. These microbial activity can have a significant effect on organic matter composition and can influence the geochemical cycles of organic carbon.

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CL and EMPA study of selected ball pegmatites from vicinities of Jelenia Góra (Karkonosze-Izera Massif, SW Poland)

Monika RUSIECKA[1], Witold MATYSZCZAK[1], Sławomir ILNICKI[1], Magdalena PAŃCZYK[2]

[1]*Institute of Geochemistry, Mineralogy and Petrology, University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, e-mail: witold.matyszczak@uw.edu.pl, slawomir.ilnicki@uw.edu.pl*
[2]*Polish Geological Institute — National Research Institute, ul.Rakowiecka 4, 00-975 Warszawa, Poland,*

Orbicular rocks are a distinct variety of more common types of rocks, such as granites, gabbros or even carbonatites (e.g. Lahti 2005). One of the regions where they occur is the north-eastern part of the Karkonosze pluton (West Sudetes, SW Poland). Known under the name of "ball pegmatite" (*Kugelgranit*), they outcrop in the area between Jelenia Góra, Kowary and Cieplice. The pegmatites consist of a nucleus, usually a large and euhedral crystal of K-feldspar (central crystal), and a double envelope. The envelope comprises two shells: the first one (micropegmatitic envelope) consists of a radiating plumose K-feldspar intergrown with quartz, and the second one is made up of fine-grained K-feldspar–quartz pegmatite. The orbicules (balls) are surrounded by granitic–to–pegmatitic matrix.

Samples from two outcrops of ball pegmatite were studied. The CL imaging was applied to study the internal structure of the constituent minerals. CL images revealed distinct zoning of the central K-feldspar with noticeable resorption texture. These features have been then confirmed during EMPA study. The compositional variations of major and trace elements along the profile throughout the central crystal were observed. The profiles showed systematical oscillation in barium content from crystal core to its margin thus constituting a pattern of systematic enrichment and depletion in Ba at the margins. The pattern of repeatedly changing maxima and minima is symmetrical with respect to the core.

Features revealed by petrographic observations, CL-imaging and chemical analysis indicate a possible correlation with recent models of genesis of orbicular rocks (Decitre et al. 2002; Grosse et al. 2010). The mode of formation of the studied ball pegmatites that can be drawn points to rapid crystallization from an undercooled melt. The growth of double shell around the nucleus of ball pegmatite was presumably preceded by the mixing-mingling process reflected by the internal textures of the central crystal of K-feldspar.

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Benzohopane series in Lower Jurassic sub-bituminous coal from "Blanowice Formation" (Southern Poland)

Maciej RYBICKI[1], Bernd R.T. SIMONEIT[2], Leszek MARYNOWSKI[1]

[1]*Faculty of Earth Sciences, University of Silesia , Będzińska 60 Str., 41-200 Sosnowiec, Poland;*
e-mail: maciej.rybicki@us.edu.pl
[2]*Department of Chemistry, Oregon State University, Corvallis, OR 97331, U.S.A.*

The Late Pliensbachian–earliest Toarcian "Blanowice Formation" is located in the Silesia-Cracow Monocline, southern Poland. This area represents the southernmost, peripheral limits of the Early Jurassic epicontinental basin in Poland. The Lower Jurassic strata in this area consist mostly of continental deposits (Gedl 2007).

Five samples of sub-bituminous coal were studied using total organic carbon (TOC) and total sulfur (TS) measurements and gas chromatography-mass spectrometry (GC-MS). Two samples were collected from the abandoned clay pit in Mrzygłód, whereas three other samples were from drill cores Wysoka Lelowska 47Ż, Żarki 90Ż, and Jaworznik 124Ż.

Total organic carbon values ranging from 48.5 to 61.9% indicate low range of coalification. TS content was diverse and varied from 0.05 to 2.78%.

The most abundant aromatic compounds for the majority of the samples are two series of benzohopanes, widespread compounds in sediments and crude oils which usually display strong resistance to biodegradation (e.g. Hussler et al. 1984; Schaeffer et al. 1995). The major series comprises C_{32}-C_{34} benzohopanes cyclized at the C-20 position (Schaeffer et al. 1995), and minor C_{31} and C_{32} benzohopanes cyclized at the C-16 position (Hussler et al. 1984). In addition there are significant amounts of di- and triaromatic derivatives of mainly the C-16 benzohopanes and lesser amounts of possibly triaromatic compounds from the C-20 benzohopanes. The total benzhopane concentrations range from 0.22 to 7.79 μg/g TOC. Such high benzohopane amounts suggest that the Blanowice coal underwent an intensive bacterial transformation.

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Al-Cr-Fe spinel alteration during serpentinisation of ultramafic rocks of the Szklary Massif

Katarzyna SADŁOWSKA[1]

[1]*Polish Geological Institute – National Research Institute, Mineral Resources Program, Rakowicka 4, 00-975 Warszawa; e-mail:katarzyna.sadlowska@pgi.gov.pl*

Mafic and ultramafic massifs surrounding the Góry Sowie block are regarded as mantle peridotites of a dismembered ophiolite suite. The ophiolite suture was formed in late Devonian as a result of the collision between the Orlik-Śnieżnik and the Góry Sowie-Kłodzko terranes. The Szklary massif is situated at the eastern border of the Góry Sowie block, in the southern part of Niemcza dislocation zone.

The Szklary Massif is composed of ultramafic rocks serpentinised to various degree and covered with tertiary laterite weathering cover. Serpentinites host ore minerals such as primary chromite, pentlandite, pyrrhotite and chalcopyrite, and secondary Fe-Cr spinel, Cr-magnetite, magnetite, Fe-Ni sulphides, and scarce native metals inclusions. The aim of this study is to provide a detailed analysis of spinel alteration and element migration during the serpentinisation process. The investigations were carried out on samples from drill cores located in the southern part of the Szklary Massif. Chemical composition in micro-area was determined using CAMECA SX 100 electron microprobe at the Polish Geological Institute – National Research Institute.

Fe-Cr spinel is the most common opaque oxide mineral in serpentinites of the Szklary Massif. On the basis of chemical composition, and the form of the spinel grains, it was possible to distinguish several generations of spinel phases. Spinel, which forms grains 2-4 mm in size, is usually rich in Al^{3+} and $Cr^{3+,}$ which is characteristic for mantle zone spinel. Detailed maps of elements distribution within Al-Cr-Fe spinel grains obtained by electron microprobe display their inhomogeneous chemical composition. The cores of these grains are usually enriched in Cr^{3+}, Al^{3+}, Mg^{2+}, Mn^{2+}, while the outer zone is depleted in these elements and enriched in Fe^{3+} and Ni^{2+}. Some of the cores may be entirely dissolved. Such wide variety of compositions and degrees of dissolution are indications of hydrothermal alteration. Alteration of spinel grains begins in the margins and terminates towards the core. Al^{3+} released from the spinel structure forms chlorite rims surrounding altered spinel. Fe^{3+} and Ni^{2+} in outer zones of spinel derive from dissolution of olivines. Ni-Fe-Co sulphides precipitate in the direct vicinity of spinel grains and along the fractures.

Primary igneous chromite, rich with Al^{3+} and Cr^{3+}, remains only as relicts in cores of altered spinel grains. The ocean-floor metamorphism results in the depletion of Al^{3+} and Cr^{3+} in the spinel core, crystallization of chlorite rims around spinel, and precipitation of Ni-Fe-Co sulphides.

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Compositional evolution of tourmalines from pegmatites at Piława Górna

Mateusz SĘK[1], Adam PIECZKA[1] , Krzysztof NEJBERT[2]

[1] *AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Department of Mineralogy, Petrography and Geochemistry, 30-059 Kraków, aleja Adama Mickiewicza 30, Poland; e-mail: msek@agh.edu.pl*
[2] *University of Warsaw, Faculty of Geology, Institute of Geochemistry, Mineralogy and Petrology, 02-089 Warszawa, Żwirki and Wigury 93, Poland*

Chemical compositions of colour-zoned tourmaline crystals (black to dark-brown in hand specimens) originated from the anatectic, hybrid NYF (niobium-yttrium-fluorine) + LCT (lithium-cesium-tantalum) Julianna pegmatitic system from the Piława Górna quarry (Góry Sowie Block, NE margin of the Bohemian Massif, SW Poland; Szuszkiewicz et al. 2013, Pieczka et al. 2015) were analysed using an electron microprobe. In thin sections, the tourmalines show a zoned texture with commonly well-separated a bluish core and a wide, olive-green to yellowish-brown mantle. Generally, the crystals represent foitite in the core, and schörl evolving to dravite in the mantle. Compositional profiles made on the crystals for the main and trace components (Fe, Mg, Al, Na. Ca, Ti, Mn) show corresponding maxima and minima, suggesting similar decreasing role of Al, Fe, Mn and Mn/(Mn+Fe) and similar increasing Ti, Mg, Ca and Na role in the pegmatite-forming melt. Positive fractionations, especially of Ti, Mg and Ca, rather atypical for the normal behaviour of the elements in the pegmatite-forming silica-bearing melts, along with reversal Mn-Fe fractionation, may suggest (1) contamination of the melt by the amphibolite host, or (2) re-work of the earlier crystallized biotite and plagioclase in more outer zones of dikes in the pegmatite system, supplying the liberated Ti, Mg, Ca and Na to the still existing melt system.

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Investigating the 2D and 3D microstructure of gas-bearing shales from the Baltic Basin by SEM imaging, XCT and FIB/SEM tomography

Piotr SŁOMSKI[1], Jacek SZCZEPAŃSKI[1], Anne PLUYMAKERS[2], Tomasz WOJCIECHOWSKI[3]

[1]*Institute of Geological Sciences, University of Wrocław , Pl. M. Borna 9, 50-204 Wrocław, Poland, e-mail: piotr.slomski@uwr.edu.pl,* jacek.szczepanski@uwr.edu.pl
[2]*PGP, Departments of Physics, University of Oslo, postboks 1048, Blindern, 0316 Oslo, Norway, e-mail:* a.m.h.pluymakers@fys.uio.no
[3]*Institute of Physics, Polish Academy of Science, Al. Lotników 32/46, 02-668 Warszawa, Poland, e-mail: twojcie@ifpan.edu.pl*

In order to reconstruct porosity, pore space distribution and their relation to mineral and organic matter content in an Early Paleozoic shale sample from the Baltic Basin we used 2D high-resolution SEM BSE imaging and 3D X-ray tomography and FIB-SEM techniques. These techniques are characterized by different measurement and spatial resolution, where increased spatial resolution (i.e. sample size) leads to decreased measurement resolution, thereby complicating upscaling.

Analysis of pore space distribution on 2D high-resolution SEM BSE images (in the range of tens of micrometers) indicates anisotropy in the pore space orientation correlated to the preferred orientation of the clay fraction minerals. We interpret this as a relicts of sediment compaction. The types of pore space comprise intraparticle pores within local clay aggregates, fracture pores, organic matter pores and interparticle pores located at the edge of the rigid grains. Interparticle and fracture pores together form about 81% of total porosity. Pore sizes in the analysed SEM BSE images fall in the range between 10 nm to 782 nm. However, the vast majority (about 80-90%) of pores does not exceed 50 nm. The mode value of pore size visible in SEM BSE image is 12.3 nm. The total porosity based on 2D SEM BSE images is only 0.6 to 0.8%. The hand specimen may have higher total porosity, but the lack of spatial resolution for 2D SEM analysis is insufficient to detect the larger pores.

In order to scale the measurements obtained from regular SEM, we complemented this with geometric analyses of 3D pore space from X-ray tomography on the centimeter scale and FIB-SEM techniques on the nanometer scale. These results confirm the geometric anisotropy in the pore space distribution, as well as in the distribution of the organic matter, also related to the orientation of the bedding plane. On the spatial resolution that can be resolved by X-ray tomography there is no observable connected structure of the organic matter and related pore spaces. However, the increased resolution that can be obtained with FIB-SEM reconstructions indicates that some of the sub-micron sized pore spaces within the organic matter are actually connected and form a network on µm scale. Our study hence suggests that for this shale the pores inside the organic matter are actually the important pathways for fluid migration. The resulting channels are parallel to the observed bedding plane, implying that diagenesis determines the macroscopic transport properties of this shale.

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Fe incorporation in MCM-41 silica mesoporous sieves using hydrothermal synthesis

Paweł SŁUPSKI[1], Piotr TUREK[1]

[1] *AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Al. Mickiewicza 30, 30-059 Kraków, Poland; paw.slu1@gmail.com*

Silica molecular sieves are well known material, but their specific properties allow for many various modifications. One way is to increase sorption capacity by a chemical modification. Iron-containing mesoporous materials were obtained by hydrothermal syntheses (Wang et al. 2014). In this procedure organic micelle were coated with iron and silica, next in thermal process organic molecules were removed leaving the Fe-silica lattice (Sener et al. 2006). Sodium silicate (Na_2SiO_3), organic surfactant (HDTMA-Br) and iron nitrate ($Fe(NO_3)_3$) were used to carry out synthesis. A number of Fe/Si ratios were applied to obtain several products that revealed differences in their chemical and structural properties. Obtained materials were analyzed by the X-Ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR) and observed using an electron microscopy.

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Paleoenvironmental conditions during the end-Ordovician mass extinction event

Justyna SMOLAREK[1], Leszek MARYNOWSKI[1], Wiesław TRELA[2]

[1]*Faculty of Earth Sciences, University of Silesia, Będzińska 60, 41-200 Sosnowiec, Poland*
e-mail: jsmolarek@us.edu.pl, leszek.marynowski@us.edu.pl
[2]*The Polish Geological Institute - National Research Institute, Zgoda 21, 25-953 Kielce, Poland, e-mail: wieslaw.trela@pgi.gov.pl*

The Late Ordovician – Early Silurian time interval was remarkable period of climate and sea-level changes documented by faunal turnover and conspicuous geochemical signatures. The switch from the greenhouse to icehouse climate mode in the Late Ordovician and return to the greenhouse conditions during the Early Silurian is considered to be one of the most spectacular biotic extinction and recovery in the Earth history (Sheehan 2001). The end-Ordovician (Hirnantian) crisis is the first globally distinct extinction during the Phanerozoic, but its causes are still not fully known. Here, we present an integrated geochemical and petrographic analysis to understand the sedimentary conditions taking place before, during and after the Late Ordovician ice age. New data from the Zbrza (Holy Cross Mountains) and Gołdap (Baltic Depression) boreholes show that, like in other worldwide sections, the total organic carbon (TOC) content is elevated in the upper Katian and uppermost Hirnantian to Rhudannian black shales, but depleted (below 1%) during most of the Hirnantian. Euxinic conditions occurred in the photic zone in both TOC-rich intervals. This is based on the maleimide distribution, occurrence of aryl isoprenoids and isorenieratane, as well as, a dominance of tiny pyrite framboids. Euxinic conditions were interrupted by the Hirnantian regression caused by glaciation. Sedimentation on the deep shelf changed to aerobic probably due to intense thermohaline circulation. Euxinia in the water column occurred directly during the time associated with the mass extinction, i.e. the onset of the end-Ordovician glaciation and sea level rise just at the O/S boundary. In contrast, based on inorganic proxies we suggest that bottom water conditions were generally oxic to dysoxic due to upwelling in the Rheic Ocean. The only episode of seafloor anoxia in the Zbrza basin was found at the O/S boundary, where all inorganic indicators (U/Th, V/Cr, V/(V+Ni) and Mo) showed elevated values typical for anoxia. Significant differences in hopanes to steranes ratio and in C27-C29 sterane distribution between the Katian, Rhudannian and Hirnantian deposits indicate changes in marine microbial communities triggered by sharp climate change and Gondwana glaciation. The increase from biomarkers of cyanobacteria (2α-methylhopanes) after the O/S boundary implied enhanced microbial activity following the mass extinction event.

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Petrology of ultramafic to felsic xenoliths from Ruddon's Point, Fife, Scotland

Paweł SOBCZAK[1], Magdalena MATUSIAK-MAŁEK[1], Brian G. J. UPTON[2], Jacek PUZIEWICZ[1], Theodoros NTAFLOS[3]

[1]*University of Wrocław, Institute of Geological Sciences, Pl. M. Borna 9, 50-204 Wrocław, Poland; e-mail: pawel.sobczak0@gmail.com*
[2] *The University of Edinburgh, School of GeoSciences, James Hutton Road, Edinburgh, UK*
[3]*University of Vienna, Department of Lithospheric Research, Althanstrasse 14, Vienna, Austria*

Permo-Carboniferous and Cenozoic mafic volcanic rocks occurring in Scotland contain xenoliths from the mantle and lower crust which provide information on the composition of the lower lithosphere. Northern Britain, especially Scotland, is remarkable for having mantle xenoliths entrained in Palaeozoic basaltic hosts. Here we present data on xenoliths in a late Carboniferous basanite intrusion at Ruddon's Point, Fife, Scotland.

The studied xenoliths comprise mostly spinel lherzolite, olivine clinopyroxenite and clinopyroxenite, but harzburgite, wehrlite, gabbro, anorthosite and also anorthoclasite, hornblendite and glimmerite occur as well. Peridotites consist of forsterite-rich olivine (Fo_{87-90}), Al-rich pyroxenes (0.25-0.31 apfu in cpx and 0.15-0.19 apfu in opx) and Cr-poor spinel (Cr-number=0.15-0.20, Mg-number=0.70). Wehrlite has cumulative texture with cumulus olivine (Fo_{83-84}) and intercumulus clinopyroxene (Mg-number=0.83-0.86, Al=0.23-0.29 apfu). Olivine clinopyroxenites and clinopyroxenites, also regarded as cumulates, are low magnesian: olivine in the former has composition of Fo_{78-82}, clinopyroxenes (cumulus phase) have Mg-number from 0.75 to 0.85 with Al ranging from 0.17 to 0.30 apfu.

Gabbro xenolith appears unmetamorphosed and was probably derived from a younger, shallower crustal level. It contains titanite and trace amounts of amphibole. Clinopyroxene in gabbro has Mg-number=0.56-0.64 and the plagioclase is essentially potassium-free ($Ab_{14-22}An_{77-86}$). Plagioclase in anorthosite has composition of $An_{54-64.}$ Anorthoclasite xenolith consists of anorthoclase accompanied by corundum, zircon, apatite, and unidentified Y- and Nb- bearing mineral.

The lherzolitic and harzburgitic xenoliths represent upper mantle rocks. The lherzolites are deduced to be residual after 10 to 15% of melt extraction whilst the harzburgite is estimated to has undergone greater depletion (18-20%). The olivine clinopyroxenites and clinopyroxenites are considered to have originated by crystal settling from an alkaline silicate melt. The gabbro may also be a crustal cumulate, but possibly from a different melt than clinopyroxenites. Corundum-bearing anorthoclasites are postulated to come from deep seated pegmatites formed by crystallization of (carbonated?) trachytic melts.

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Detrital zircon ages from a Lower Ordovician quartzite of the Orlica-Śnieżnik Dome (Central Sudetes, Bohemian Massif): Evidence for Saxothurigian affinity

Jacek SZCZEPAŃSKI[1], Krzysztof TURNIAK[1], Robert ANCZKIEWICZ[2], Paulina RUDNICKA[1]

[1]*Institute of Geological Sciences, University of Wrocław, Pl. M. Borna 9, 50-204 Wrocław, Poland, e-mail: jacek.szczepanski@uwr.edu.pl.*
[2]*Institute of Geological Sciences PAN, Cracow Research Centre, ul. Senacka 1, 30-001 Krakow, Poland, ndanczki@cyf-kr.edu.pl*

The Neoproterozoic to Ordovician rock successions have lastly been reported from the Orlica-Śnieżnik Dome (OSD) located in the Central Sudetes (Jastrzębski et al. 2016; Mazur et al. 2012; Szczepański, Ilnicki 2014). Consequently, the OSD may represent a vestige of recycled Saxoturingian crust emerging from below rock complexes representing strikingly different provenance. In this context remarkable is the thin horizon of the light Goszów Quartzites (GQ) exposed in the eastern part of the OSD. The horizon is believed to be of Early Ordovician age and contradictory interpreted as a fragment of continuous succession collectively referred to as the Stronie-Młynowiec Group (SMG) and comprising the Młynowiec (MF), the Stronie Formations (SF) and the Goszów Quartzites (GQ; Jastrzębski et al. 2016) or representing the youngest Early Ordovician member of the three distinct volcano-sedimentary successions represented by MF, SF and GQ (Mazur et al. 2012). Similar, but not previously dated, light quartzites are also known from the western limb of the OSD (the Bystrzyckie Mts.). We studied morphology and age of zircon grains from the light quartzites exposed in the Bystrzyckie Mts. Our aim was to constrain provenance and maximum depositional age of the investigated quartzites and combining our age data with available information on chemical composition of volcano-sedimentary successions (Ilnicki et al. 2013; Szczepański, Ilnicki 2014) to put constraints on the provenance of the volcano-sedimentary sequences exposed in the OSD.

Age spectra obtained for zircon concentrates from examined light quartzites define few age clusters. The best represented are Cambro-Ordovician (from 475 to 500 Ma) and Neoproterozoic (from 620 to 880 Ma) age clusters. Less significant are Paleoproterozic and Archean age clusters. Moreover, a distinctive feature of the analyzed groups of zircons is lack of Mesoproterozoic grains. We interpret the age of the youngest cluster documented in the Bystrzyckie quartzites as maximum depositional age for the protolith. We also suggest that age spectra obtained from the whole analyzed population of grains reflect similarities of the investigated quartzites to well-defined horizon of the GQ known from the eastern part of the OSD. Consequently, obtained data points to Saxothuringian affinity of crustal basement exposed in the OSD and strongly advocates recently proposed terrane model suggesting that the OSD represent allochtonous and reworked part of the Saxothuringian basement (Chopin et al. 2012).

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Trace elements vs. geochronology – zircon from Góry Sowie granulite study

Katarzyna WALCZAK[1], Robert ANCZKIEWICZ[2], Daniela RUBATTO[3], Jacek SZCZEPAŃSKI[4]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland, katarzyna.walczak@agh.edu.pl*
[2]*Institute of Geological Sciences PAN, Cracow Research Centre, ul. Senacka 1, 30-001 Krakow, Poland, ndanczki@cyf-kr.edu.pl*
[3]*Institute of Geological Sciences, University of Bern, Switzerland, daniela.rubatto@geo.unibe.ch*
[4]*Institute of Geological Sciences, University of Wrocław, Pl. M. Borna 9, 50-204 Wrocław, Poland, jacek.szczepanski@uwr.edu.pl.*

Góry Sowie Block (GSB) is a tectonic unit located at the NE margin of the Bohemian Massif in SW Poland. GSB is divided by the Sudetic Marginal Fault into two parts; mountainous SW part (Sowie Mts) and NE part which belongs to the Fore-Sudetic Block. It is composed of high-grade polimetamorphic rocks, mainly paragneisses and migmatites accompanied by minor granulite and meta-peridotite bodies (e.g. Kryza et al. 1996; Kryza, Pin 2002).

Although numerous geochronological studies of GSB metamorphic rocks have been undertaken, only sparse of them regard UHT/HP event and point to ca. 395-400 Ma (Brueckner et al. 1996; O`Brien et al. 1997; Kryza, Fanning 2007).

Our U-Pb SHRIMP dating of zircon metamorphic overgrowths from Góry Sowie granulite (Zagórze Śląskie) points to slightly lower age of ca. 388 Ma. However, cathodoluminescence images reveal cores and two distinct types of overgrowths, which encouraged us to combine SHRIPM and CL data with LA ISP MS in situ geochemical studies of dated zircon grains to look into trace elements content in distinct internal zones.

REE studies revealed presence of three distinct internal zones in zircon:

(a) The most internal, core – with geochemical characteristics typical of magmatic zircon (high Lu/Gd ratios, high positive Ce anomaly), with wide range of SHRIMP inherited ages ranging from ca. 415 to ca. 1600 Ma.

(b) Overgrowths (I) with dark CL luminescence, overgrowing directly cores, are of metamorphic origin, with features typical for eclogite facies conditions (typified e.g. by lack of Eu anomaly).

(c) Overgrowths (II) with bright CL luminescence, overgrowing cores and/or overgrowths (I), are of metamorphic origin, with strongly pronounced Eu negative anomaly.

Detailed investigations of trace elements content in distinguished types of overgrowths emphasize differences between both types of overgrowths shown by: Lu/Gd, Th/U ratios, Ce and Eu content as well as crystallisation temperature estimated using Ti in zircon thermometer (Watson et al. 2006). Nonetheless, ages of both types of zircon overgrowths remain indistinguishable within error: 387.9 ± 2.3 Ma and 388.8 ± 2.0 Ma respectively for first (I) and second (II) types of overgrowths.

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U-rich Monazite-(Ce) from granitic pegmatites at Lutomia and Michałkowa – preliminary data

Adam WŁODEK[1], Adam PIECZKA[1], Anna GROCHOWINA[1]

[1]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059 Kraków, Poland; e-mail: wlodek@agh.edu.pl*

Introduction

Granitic pegmatites at Lutomia and Michałkowa are Variscan-age, metamorphic-origin bodies, related to anatectic processes which are located in NE part of GSB (Góry Sowie Block). Both pegmatites are relatively low-fractionated, LCT-type bodies with primitive mineral composition dominated by quartz, microcline, albite, muscovite, biotite and black tourmaline. Beside these typical pegmatitic minerals, both bodies contain accessory phosphate nodules composed of primary magmatic phosphates – graftonite, sarcopside ± tryphylite. In this work we present preliminary chemical characteristics of two chemical types of monazite-(Ce) from both pegmatitic bodies: (type 1) U-rich monazite associated with primary phosphates and (type 2) Th-enriched monazite associated with aluminosilicates.

Chemical compositions of Monazite-(Ce)

Monazite-(Ce) of the first type, relatively more common, is associated with Fe-Mn-Mg-Li phosphates – sarcopside (Michałkowa pegmatite – MP) or tryphylite-sarcopside intergrowths (Lutomia pegmatite – LP). Type 1 monazite is characterized by very low Y+HREE contents, with LREE/(LREE+HREE) atomic ratio reaching up to 0.99 (MP and LP), very high Uranium content (8.18 wt.% UO_2 for MP and 7.99 wt.% UO_2 for LP) with U/(U+Th) atomic ratio up to 0.94 (MP) and 0.92 (LP), elevated CaO contents up to 1.98 wt.% (MP) or 2.04 wt.% (LP), and negligible SiO_2 contents, reaching up to 0.03 wt.% (both MP, LP).

Monazite-(Ce) of the second type, less common, occurs in association with biotite (MP) or albite and biotite (LP). In Michałkowa pegmatite, monazite of type 2 forms crystals with sizes not exceeding 100nm, which are below analytical capabillity of EPMA. In Lutomia pegmatite crystals of this monazite are relatively larger and reach up to 50μm in size. These crystals have higher concentration of Y+HREE with LREE/(LREE+HREE) ratio up to 0.85, much lower contents of uranium (up to 1.67 wt.% UO_2) with lower U/(U+Th) atomic ratio (up to 0.27), higher contents of SiO_2 (up to 0.20 wt.%) and lower CaO content <1.4 wt.%.

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Studies of the metamorphic evolution of serpentinites and metagabbros from the Central-Sudetic ophiolites (SW Poland)

Piotr WOJTULEK[1], Michał BUKAŁA[2], Iwona KLONOWSKA[3], Jarosław MAJKA[2,3]

[1]*Institute of Geological Sciences, University of Wrocław, pl. M. Borna 9, 50-204 Wrocław, Poland; e-mail: piotr.wojtulek@interia.pl*
[2]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków, Poland*
[3]*Department of Earth Sciences, Uppsala University, Villavägen 16, SE-752-36 Uppsala, Sweden*

The Ślęża and Braszowice-Brzeźnica are mafic-ultramafic massifs occurring in the Sudetic Foreblock, interpreted as Central-Sudetic ophiolites. They are neighboring the Góry Sowie Block, which consists of gneisses with remnants of HT-HP granulites and garnet peridotites. Ages of magmatic crystallization of the Ślęża ophiolite and HP-HT metamorphism of rocks from the Sowie Góry Block are similar – ca 400 Ma (Brückner et al. 1996; Kryza, Pin 2010). In this study, we present data of deserpentinization phases from serpentinites and thermodynamic modelling of metagabbro from the Mnich Hill in the Braszowice-Brzeźnica Massif.

Serpentinites occurring in the Ślęża and Braszowice-Brzeźnica Massifs are refractory in terms of lack of trace elements. They are mostly non-pseudomorphic, antigorite ones, including scarce pseudomorphic domains. Locally, they contain non-serpentine phases (olivine, clinopyroxene) with magnetite inclusions, displaying pseudocleavage or occurring as microcrystalline olivine-clinopyroxene-magnetite aggregates ('brownish aggregates') with bastite and mesh textures. Magnetite-bearing olivine has various Fo (86.8-92.7) and NiO (0.02-0.55 wt%) contents olivine from 'brownish aggregates' has NiO = 0.20-0.41 wt%. Clinopyroxene from 'brownish aggregates' has low Al_2O_3 and Cr_2O_3 contents (0.00-1.00 wt% and 0.20-0.60 wt%, respectively) and high Mg# (96.0–98.1). Metagabbros from both massifs are highly altered; they consist mainly of partly uralitised clinopyroxene and saussuritised plagioclase.

Mineral assemblages occurring in serpentinites suggest following alterations: (1) low-T serpentinization I producing pseudomorphic lizardite-chrysotile serpentinites, (2) antigorite recrystallization, (3) deserpentinization forming secondary olivine with magnetite inclusions and 'brownish structures' and (4) high-T serpentinization II producing antigorite intergrowths. Occurrence of deserpentinization mineral assemblage (antigorite-olivine-diopside) suggests peak temperatures at ~380-460°C (CMASH phase diagram of Berman et al. 1986). Preliminary thermodynamic modelling of the metagabbro gave minimum temperature of ~400°C at ~4 kbar pressure.

Mineral composition of serpentinites and metagabbros implies low grade metamorphic conditions of their alteration and two metamorphic stages: (1) prograde antigorite recrystallization and deserpentinization, and (2) retrograde, secondary antigorite serpentinization. Our observations suggest low grade metamorphic evolution of rocks belonging to the Central-Sudetic ophiolites.

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Petrography and possible provenance of natural stones found in the Lubiąż Abbey (SW Poland)

Katarzyna ZBOIŃSKA, Mateusz SZADKOWSKI, Wojciech BARTZ

Institute of Geological Sciences, University of Wrocław , Maxa Borna Square 9; e-mail: kzboinska@gmail.com

Lubiąż Abbey is a monumental, post-Cistercian monastery complex, one of the best in its class throughout the world. It was founded in 1175 by Bolesław I the Tall, Duke of Wrocław. In the centuries following, the Abbey was successively enlarged and rebuilt, mostly in the Baroque style. Shortly before the secularization of the Abbey in 1810, it consisted of a number of buildings, of which the most important were: the Abbatial Palace, the church of the Assumption of the Blessed Virgin Mary, the cloister and the St. Jacob's church. The aim of this study is to characterize the natural rocks used in the architectural details of sacral objects, and attempt to identify the provenance of investigated material.

We analyzed 11 samples from two of the Abbey's buildings: the Assumption of the Blessed Virgin Mary Church (8 samples of sandstones from window frames, 2 samples of limestones from the floor and 1 sample of limestone from the tombstone of abbot Matthäus Rudolf von Hennersdorf) and 2 samples of sandstones from the window frames of the St. James Church. Samples were analyzed by means of a polarizing microscope (PM) and computer image analysis (CIA). We also used stable isotope geochemistry for selected limestone samples.

Obtained petrographic data (similar mineral composition, grain size distribution) suggests that the sandstones can be classified as quartz arenites, representing Upper Cretaceous joint sandstone from Lower Silesia.

Limestones from the Assumption of the Blessed Virgin Mary Church floor are probably Ordovician limestones from Öland Island, due to the occurrence of Lower Palaeozoic fossils, as well as historical evidence.

The sample of red nodular limestone (the so-called 'red marble'), from the tombstone of abbot, is macroscopically similar to Jurassic limestones from Austria, Hungary and Slovakia. However, the stable isotope composition of this sample (^{13}C and ^{18}O) is completely different than those of Hungarian and Austrian limestones (Pintér et al. 2004). Thus we conclude that it is a limestone from Old Ľubovňa, Slovakia, as suggested by historical data.

Acknowledgements: The research was supported by the National Science Centre Project (DEC-2012/07/B/ST10/03820).

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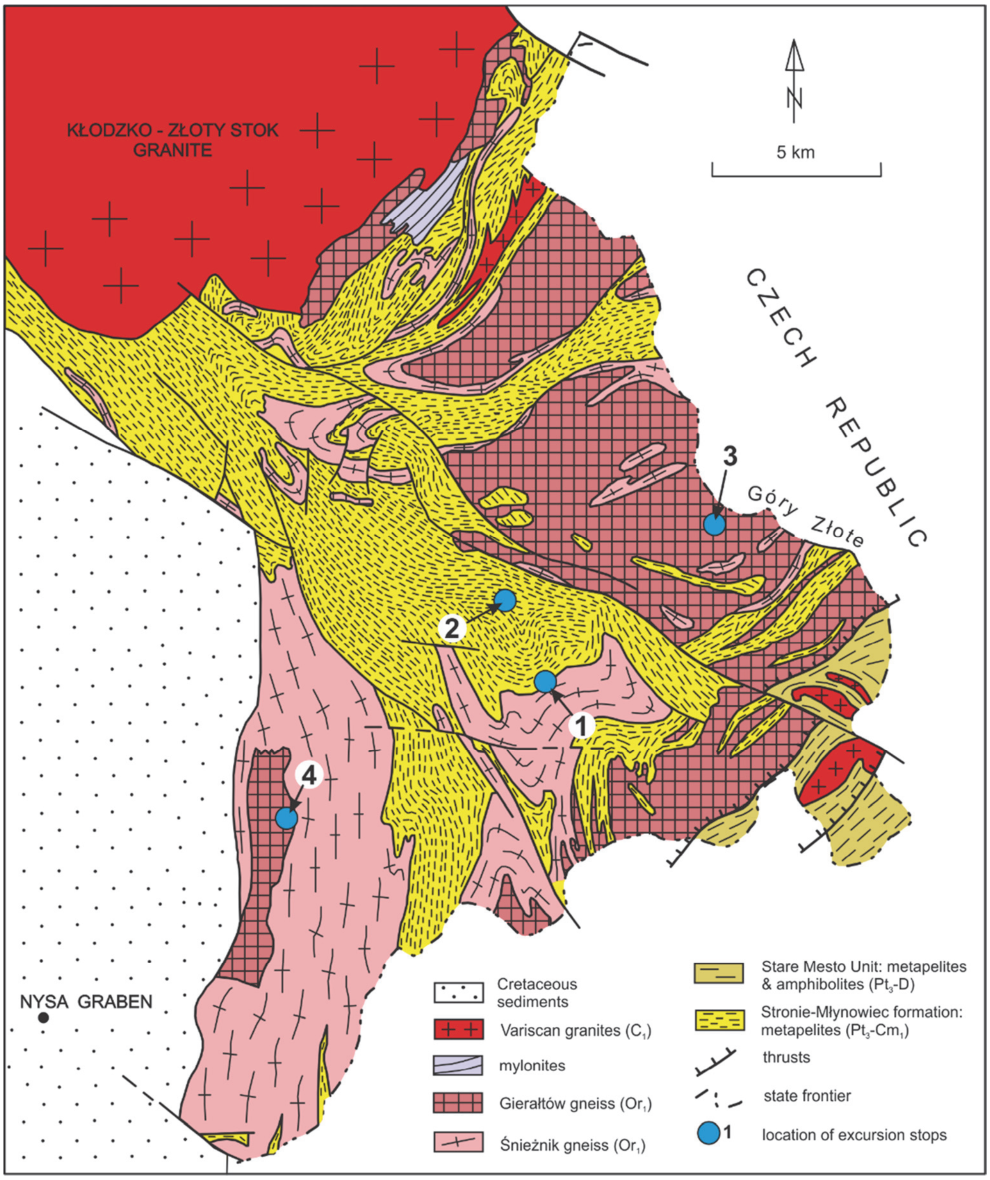
Subduction systems in the Sudetes and related areas

Field trip guide


KŁODZKO - ZŁOTY STOK
GRANITE
5 km
CZECH REPUBLIC
Góry Złote
NYSA GRABEN
1
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Cretaceous sediments
Variscan granites (C1)
mylonites
Gierałtów gneiss (Or1)
Śnieżnik gneiss (Or1)
Stare Mesto Unit: metapelites & amphibolites (Pt3-D)
Stronie-Młynowiec formation: metapelites (Pt3-Cm1)
thrusts
state frontier
location of excursion stops

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Stop 1. Marble quarry located on the SW branch of Krzyżnik Mt.

Mirosław JASTRZĘBSKI[1]

[1]*Institute of Geological Sciences PAN, Research Centre in Wrocław, Podwale St. No. 75, PL-50449 Wrocław, Poland; mjast@interia.pl.*

Location: N50.27791 E16.86586

Marbles of the Młynowiec-Stronie Group are several meters to ~400 meters thick and occur as interlayers or lensoid-shaped bodies within mica schists (e.g. Kuźniar 1960; Cwojdziński 1983; Karwacki 1990; Sawicki 1995 and references therein; Koszela 1997; Don et al. 2003). Marbles exposed within the quarry of interest (Fig. 1a) are white, pink or grey, and are predominantly medium-grained. They consist of calcite (>90 vol%), dolomite, quartz and phlogopite, with occasional muscovite, tremolite and clinozoisite-epidote. Medium-grained calcite, and usually finer-grained dolomite, are concentrated in monomineralic laminae and/or lenses (Fig. 1b). These marbles were exploited in the area of Krzyżnik Mt. for decorative purposes until the 2000's. The marbles are surrounded by grey to brownish, porphyroblastic mica schists consisting mainly of quartz, muscovite, biotite, garnet, ilmenite, and staurolite, with rare kyanite, chlorite, rutile and chloritoid (e.g. Grzechnik 1989, Jastrzębski 2009) (Fig. 1c).

Sharp contacts between marbles and mica schists, in addition to very well-preserved deformational structures reflecting the tectono-metamorphic history of the Orlica-Śnieżnik Dome (OSD), can be observed at this stop. The main structural feature exposed within the quarry rocks is an outcrop-scale, tight, recumbent fold accompanied by smaller-scale, lower-order parasitic folds (Fig. 1a) (see also Fig. 4 in Don et al. 2003). Axes of these folds plunge shallowly to N to NW. The main foliation in the marbles and mica schists are axial-planar to these folds and dip at low/moderate angles towards the NE (S2 planes). In the marbles, the axial-planar foliation (S2) is formed by the parallel arrangement of flattened dolomite, phlogopite and tremolite (Fig. 1b). In the mica schists, the penetrative axial-planar schistosity (S2) is defined by an alternation of quartz and phyllosilicates laminae (Fig. 1c). The penetrative metamorphic foliations in both types of rocks contain relics of an earlier metamorphic foliation (S1). In calcitic marbles, the early S1 foliation is expressed as a folded quartz lamination that is oblique to the penetrative axial-planar foliation (Fig. 1b). In the mica schists, S1 is defined by chlorite-chloritoid-muscovite inclusion trails in garnets (Fig. 1c).

Calcite-dolomite thermometry applied to marble samples collected in this quarry indicate that the main metamorphic foliation (S2 planes) developed at the peak temperature of metamorphism at 610-630°C (Jastrzębski 2009) (Fig. 1d). Conventional thermobarometry and thermodynamic modeling performed on the Grt and St-bearing mica schists collected from the Krzyżnik area indicate that the schistosity formation event took place at conditions between 580 to 650°C, and between 6 to 9 kbar (Murtezi 2006; Jastrzębski 2009) (Fig. 1d). The transition from the garnet-core assemblage of chloritoid-chlorite-garnet (core) (S1 planes), to the matrix assemblage of staurolite-biotite-garnet (rim) (S2 planes) was related to the progression of Barrovian metamorphism from greenschist to amphibolite facies conditions (Murtezi 2006). In conclusion, maximum burial depths determined for rocks at Stop 1 do not exceed 30 km, which significantly contrasts the burial depths calculated for the OSD granulites and eclogites (Stops 3 and 4).

Mica schists collected from upper levels of the quarry yield an Sm-Nd (Grt-WR) age of ~347 Ma (Jastrzębski 2009), whereas monazite Th-U-total Pb geochronology revealed a wide range of ages that cluster around 370 Ma (Jastrzębski et al. under review) (Fig. 1e). Comparison of the geochronological data obtained for this exposure with data obtained in the other parts of the OSD suggests prolonged Variscan metamorphism that initiated at 360-370 Ma and continued to ~330 Ma.

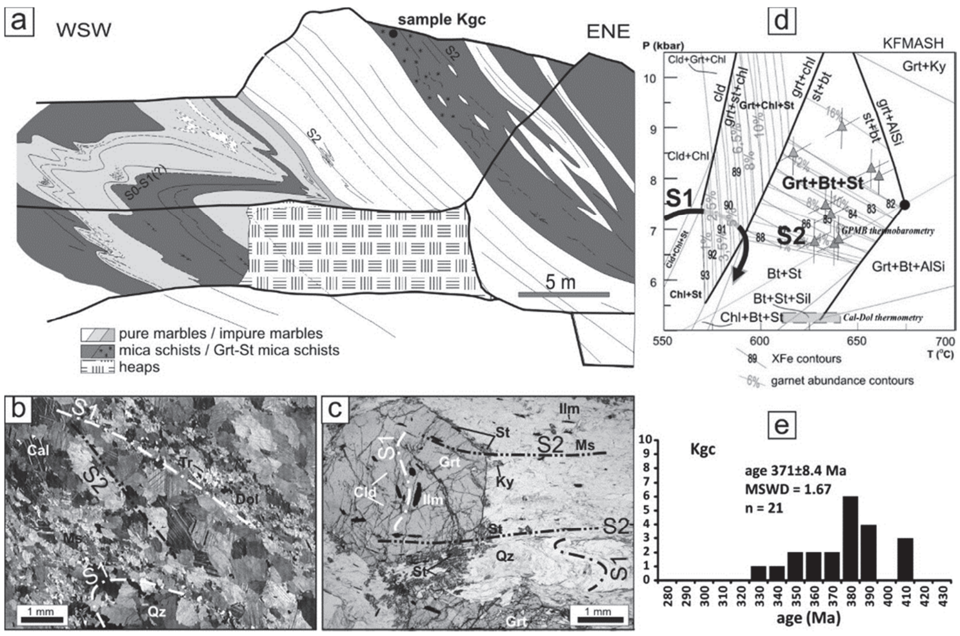

Fig. 1. Marbles and mica schists from Krzyżnik quarry - Stop 1. (a) Sketch of the quarry. (b-c) Photomicrographs showing the relationships between deformation and metamorphism in marbles (a), and mica-schists. (d) Results of conventional thermobarometry (Jastrzębski 2009) and thermodynamic modeling (Murtezi 2009) applied for to mica schists from the quarry. (e) Results of Th-U-total Pb dating of monazites.

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Stop 2. Quartzites in the village of Stara Morawa

Mirosław JASTRZĘBSKI[1]

[1]*Institute of Geological Sciences PAN, Research Centre in Wrocław, Podwale St. No. 75, PL-50449 Wrocław, Poland; mjast@interia.pl.*

Location: N50.26574 E16.87419

The light quartzites of the Orlica-Śnieżnik Dome (OSD) are 10's of kilometer-long continuous bodies that are ~15 meter thick and occupy a specific structural position in the OSD (Don et al. 2003). These rocks separate the mica schists of the Stronie Formation from paragneisses of the Młynowiec Formation and orthogneiss of the Śnieżnik Formation (e.g. Don, Dowidar 1988). Interpretations of the protolith, age of formation and tectonic significance for the OSD quartzites have been the subject of a major debate among geologists through past decades (e.g. Smulikowski 1979; Cymerman 1997; Don et al. 2003; Jastrzębski et al. 2010, 2016; Mazur et al. 2012; Szczepański, Ilnicki 2014).

The outcrop at Stop 2 is situated west of the village of Stara Morawa and forms an approximately 100 m wide E–W oriented rock ridge. Within this exposure, three petrographic varieties of light quartzites were distinguished: pure quartzites that are massive, fine-grained, and are mainly composed of quartz (≥80 vol%) and muscovite (~15 vol%); muscovite-rich quartzites (transitional rocks to mica schists) that are characterized by alternating laminae of quartz (60–70 vol%), phyllosilicates (muscovite, chlorite > biotite), and garnet and staurolite; and K-feldspar quartzites composed of quartz (≥80 vol%) and K-feldspar (~5 vol%). The quartz pure and mica-rich quartzites are the predominate types exposed in the outcrop. They form thin interlayers with interfingering contacts. Interlayers of K-feldspar quartzites are sporadic.

Well-preserved deformational structures in quartzites from the Stara Morawa can be observed at this stop. Similar to the mica schists and marbles from Stop 1, the penetrative foliation is an axial planar fabric to the tight N–S trending folds. This main metamorphic fabric (S2) is defined by a quartz grain-shape fabric, sometimes emphasized by alternating laminae of quartz and phyllosilicates. Relics of the earlier metamorphic foliation (S1) occur in form of folded quartz laminations (Fig. 1a). The S1 planes in the muscovite-rich quartzites are defined as chlorite-chloritoid-muscovite inclusion trails in garnet porphyroblasts (Fig. 1b), similar to the S1 planes preserved in mica schists from the Krzyżnik area. In addition, chlorite and muscovite flakes occur in pressure shadows between fragments of garnet and staurolite which were occasionally stretched and boudinaged in N–S direction due to a subsequent mylonitic deformation (S3 planes) (Fig. 1c). This means that both the penetrative foliation and N–S trending lineation are polyphase structures developed during the progression and retrogression of the regional metamorphic event. Thermodynamic modeling performed on the muscovite-rich quartzites collected from the visited exposure indicate that development of the tight folds and penetrative S2 metamorphic foliation in the quartzites were related to metamorphic progression from

500ºC to 640ºC at 6-7 kbar (Fig. 1d). Subsequently, under retrogressive conditions of 450ºC and 3-4 kbar, the foliation was reactivated as a result of ductile shearing and N–S directed extension (Jastrzębski et al. 2016). The P-T-deformational evolution of the quartzose rocks from Stara Morawa clearly corresponds to that recognized for mica schist from the Krzyżnik Mt. (Stop 1).

Electron microprobe monazite dating performed on the same sample provided wide range of Th-U-total Pb dates ranging from 310 to 370 Ma, suggesting a prolonged Variscan metamorphic process. More than half of the dates fall between 330 and 350 Ma. The weighted average Th-U-total Pb age of ~339 Ma probably reflects N–S-oriented late Variscan tectonic movements (Jastrzębski et al. 2016) (Fig. 1e).

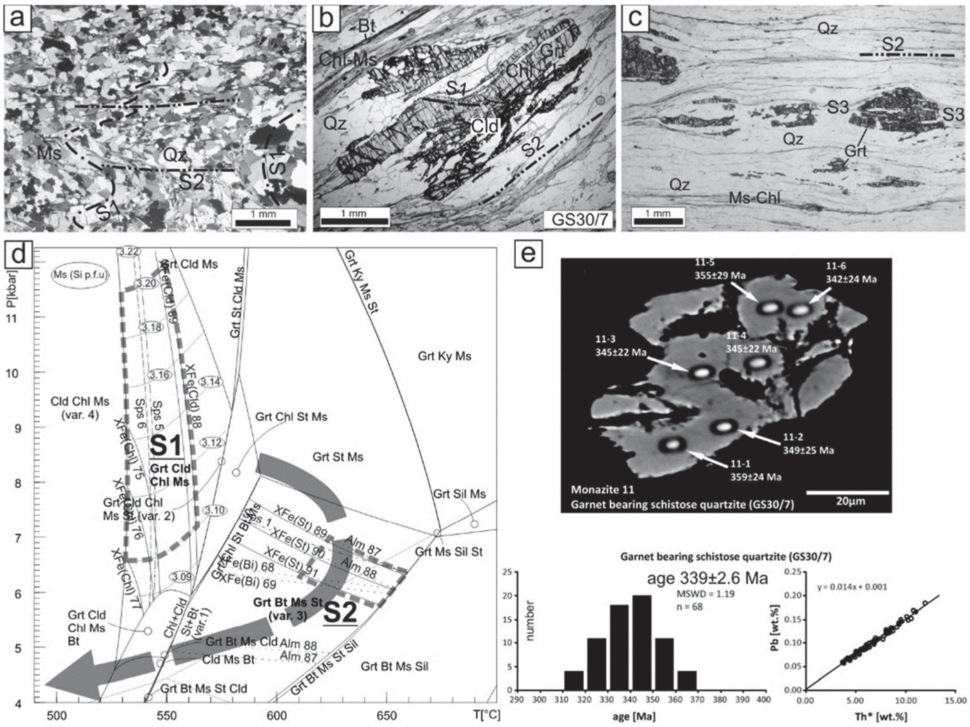

Fig. 1. Quartzites from Stara Morawa (Stop 2). Photomicrographs showing the relationships between deformation and metamorphism in pure quartzites (a), and muscovite-rich quartzites (b and c), (d) Mineral stability phase diagram calculated in the system MnKFMASH, the compositional isopleths for the minerals defining the S1 and S2 foliations, and the possible P-T path. (e) Results of the Th-U-total Pb dating of monazites.

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Stop 3. Geochronological and petrological constraints on the rise of the Orlica-Śnieżnik Dome, NE Bohemian Massif, SW Poland

Jacek SZCZEPAŃSKI[1], Robert ANCZKIEWICZ[2], Katarzyna WALCZAK[3]

[1]*Institute of Geological Sciences, University of Wrocław, Pl. M. Borna 9, 50-204 Wrocław, Poland, jacek.szczepanski@uwr.edu.pl.*
[2]*Institute of Geological Sciences PAN, Cracow Research Centre, ul. Senacka 1, 30-001 Krakow, Poland, ndanczki@cyf-kr.edu.pl*
[3]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, Mickiewicza 30, 30-059Kraków, Poland, katarzyna.walczak@agh.edu.pl*

Location: rock scarp on the right bank of the Biała Lądecka River, Stary Gierałtów village, 7 km E of Stronie Śląskie, N50.30825 E16.93509

Granulites cropping out near Stary Gierałtów form a part of an up to 2 km wide and 12 km long body trending from SW to NE (Fig. 1A). The main lithological type is a felsic granulite grading into an omphacitic mafic granulite (Fig. 1C). The protolith of the granulites has been described as interlayered acidic and basic tuffs, or as bimodal volcanics with a small admixture of sedimentary material. The felsic granulites are composed of quartz, plagioclase, K-feldspar, garnet, kyanite and biotite. In comparison, mafic granulites are additionally comprised of omphacite. Rutile, ilmenite and zircon are common accessories.

Granulites are predominantly surrounded by high grade gneisses (mainly of Gierałtów type) and by subordinate high grade metasediments of the Młynowiec-Stronie Group (Fig. 1A). Recently proposed models explaining the tectonic position of granulites assumes that they were exhumed along a nearly vertical channel initiated by buckling of crustal layers of thickened Saxothuringian crust due to collision between the Saxothuringian, Tepla, Barandian, and Brunovistulian terranes (Štípska et al. 2004; Chopin et al. 2012). Peak pressures for the granulites are believed to lie within the coesite stability field (2.8-3.0 GPa and 900-1100°C; Bakun-Czubarow 1991; Kryza et al. 1996; Bröcker, Klemd 1996; Klemd, Bröcker 1999). However, Štípska et al. (2004) and Budzyń et al. (2015) have questioned these estimations and concluded considerably lower peak PT conditions of 1.8 GPa at 900°C and 2.0-2.2 GPa at 920-970°C, respectively. A recent study by Ferrero et al. (2015), based on nano-granite inclusions found in the garnet porphyroblasts of the granulites, suggested peak PT conditions of metamorphism at 2.5-2.7 GPa and 800-900°C.

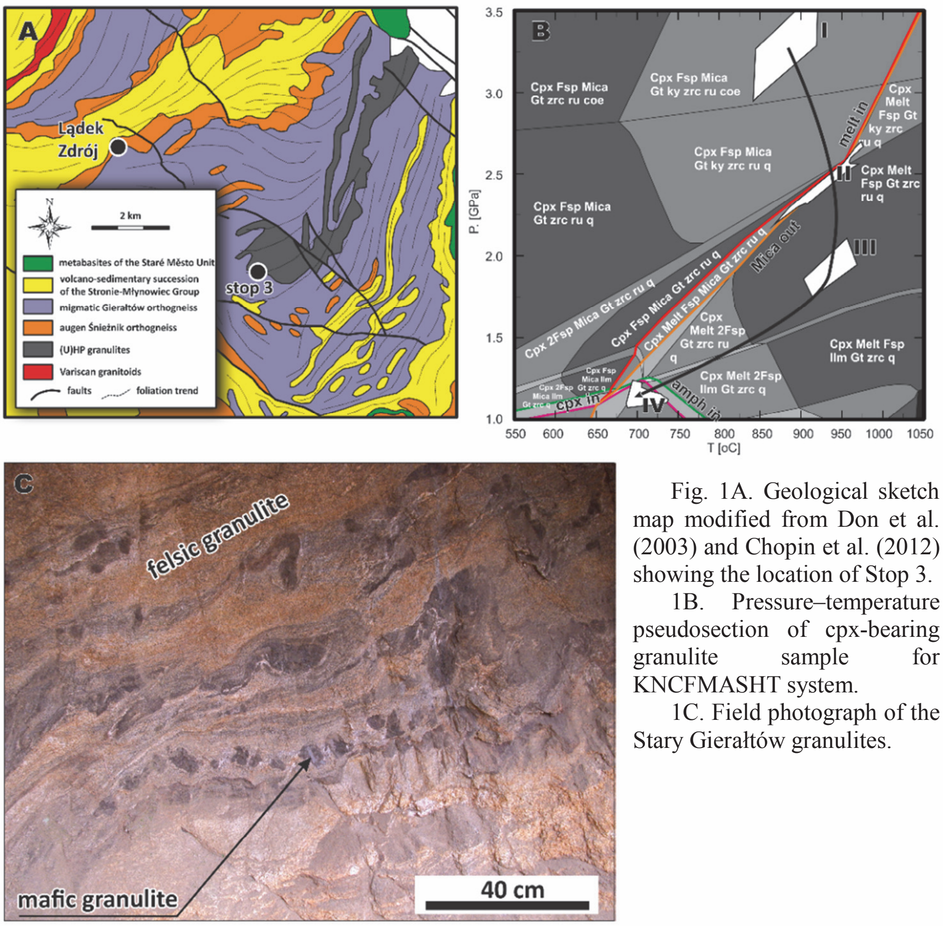

Fig. 1A. Geological sketch map modified from Don et al. (2003) and Chopin et al. (2012) showing the location of Stop 3.

1B. Pressure–temperature pseudosection of cpx-bearing granulite sample for KNCFMASHT system.

1C. Field photograph of the Stary Gierałtów granulites.

In order to decipher the metamorphic record preserved in the granulites, we performed thermodynamic modeling of mineral assemblages coupled with Lu-Hf and Sm-Nd garnet dating of two cpx-bearing granulite samples. The calculated P-T pseudosection is presented in Fig. 1B. To reconstruct the P-T path, we used chemical zonation patterns recorded by the two garnet types with different zonation trends interpreted as: 1) relic growth zonation observed in larger crystals; and 2) thermally relaxed profiles observed in vast majority of the remaining grains. The latter types of garnet grains are additionally characterized by the frequent occurrence of nano-granite inclusions in their cores, indicating their growth in the presence of melt (Ferrero et al. 2015). The cores of the first type of garnets indicate crystallization above the solidus in an ultra-high pressure field (Fig. 1B, field I, pressures of 3.0-3.5 GPa at 850-920°C temperature). These estimates, however, require some caution as coesite has so far not been found in these rocks. The presence of pseudomorphs after coesite were postulated by Bakun-Czubarow (1992) but later questioned by Štípska et al. (2004). P-T conditions recorded by the second type of garnet thermally relaxed are just below solidus line (Fig. 1B, field II).

Lu-Hf dating of peritectic garnet from two cpx-bearing granulite samples constrained the time of its initial growth at 346.9±1.2 and 348.3±2.0 Ma. Isopleths corresponding to rims of larger garnet grains with relic-growth zonation, documented in the investigated sample of cpx-bearing granulite, cross in a relatively small P-T space between ca. 1.75-2.00 GPa at 900-950°C (Fig. 1B, field III). Consequently, the metamorphic evolution of cpx-bearing granulites between points A and C suggests a nearly isothermal decompression by ca. 1.0 to 1.5 GPa.

The final stage of metamorphic evolution of the cpx-bearing granulites may be constrained to 1.20-1.25 GPa and 690-760°C (Fig. 1B, field IV). Thus, the second part of the P-T path, which is approximately horizontal in the analyzed P-T space, indicates nearly isobaric cooling. In-situ U-Pb SHRIMP dating of zircon from the same granulite provided an age of 342.2±3.4 Ma. Ti thermometry indicates crystallization at 760-830°C, pointing to zircon formation on a retrograde path. Heavy REE garnet rim - zircon rim partitioning indicates equilibrium growth. Hence, the U-Pb zircon date is interpreted as marking the terminal phase of garnet crystallization which lasted about 5 Ma. All Sm-Nd garnet ages obtained for cpx-bearing granulites are identical and consistently younger than the corresponding Lu-Hf dates. They are interpreted to reflect cooling of granulites through the Sm-Nd closure temperature at about 337 Ma.

The estimated P-T-t path documents a ca. 10 Ma evolution cycle of the OSD characterized by two distinct periods (Fig. 2): (1) from 348 - >342 Ma corresponds to a nearly isothermal decompression resulting from crustal scale folding and vertical extrusion of granulites (Fig. 2A and B); and (2) from >342-337 Ma which corresponds to a fast, nearly isobaric cooling which becomes very rapid towards the end of this period. The latter stage is correlated with horizontal spreading of uplifted OSD rocks (Fig. 2C).

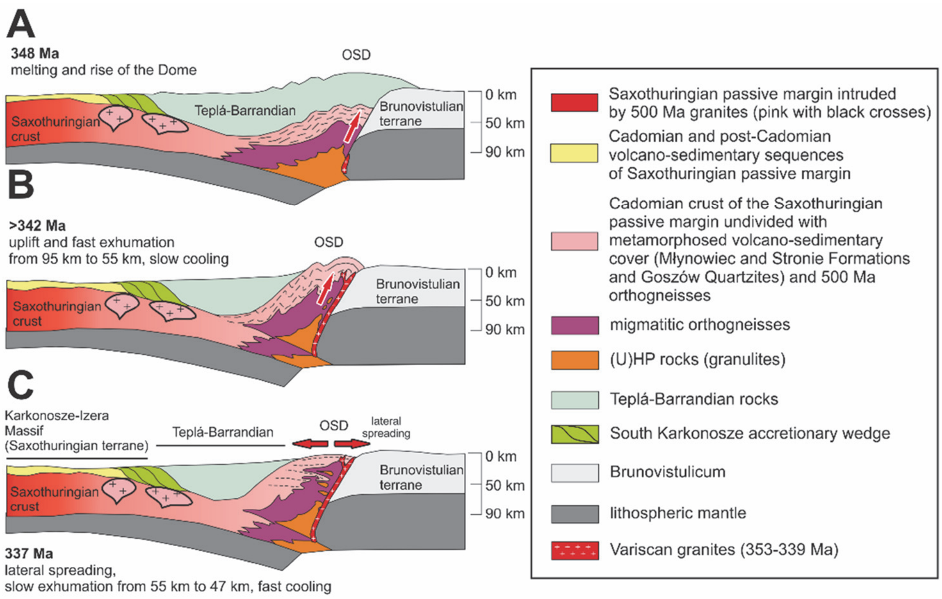

Fig. 2. Tectonic model of the OSD formation (after Štípska et al. 2004 and Chopin et al. 2012; modified).

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Stop 4. Eclogites at Góra Parkowa in Międzygórze

Jarosław MAJKA[1,2], Katarzyna WALCZAK[2], Iwona KLONOWSKA[1], Karolina KOŚMIŃSKA[2,3]

[1]*Uppsala University, Department of Earth Sciences, Villavägen 16, SE – 752 36 Uppsala, Sweden; e-mail: jaroslaw.majka@geo.uu.se*
[2]*AGH – University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection, al. Mickiewicza 30, 30-059 Kraków, Poland*
[3]*Rensselaer Polytechnic Institute, Department of Earth and Environmental Sciences, 110 8th Street, 12180 Troy, NY, USA*

Location: N50.22971, E16.76833

The eclogites in the Międzygórze area are hosted by the Gierałtów gneisses. They crop out in several places including Góra Parkowa. They have been a subject of several petrological and geochronological studies, yet both the metamorphic conditions and age of their formation are a matter of debate.

A detailed geothermobarometrical study by Bröcker and Klemd (1996) yielded P-T conditions of min. 27 kbar and 700-800°C, pointing to possible ultrahigh pressure (UHP) origin of these eclogites. Similarly, Bakun-Czubarow (1998) provided a P-T estimate of 33 kbar at 770°C confirming their UHP origin. A more recent study by Štípská et al. (2011) questioned the UHP origin of these rocks. These authors claimed that the garnet zoning was incorrectly interpreted by the previous authors and therefore their P-T estimates are invalid. According to Štípská et al. (2011), the maximum P-T recorded by the Międzygórze eclogites was 19-22 kbar at 700-750°C.

The most recent studies by Majka et al. (2016) and Młynarska et al. (this volume) point to a UHP origin. According to these authors, the Międzygórze eclogite is finely foliated with millimeter-scale garnet and omphacite dominated bands. Garnet forms subhedral to euhedral porphyroblasts, in rare cases containing tiny inclusions of kyanite and rutile and somewhat bigger inclusions of quartz. Omphacite and to a lesser degree kyanite, phengite and quartz form the main matrix assemblage. Accessory rutile, apatite, zircon and Fe-oxides are also present in the matrix. Zoisite is found partly or completely overgrown by garnet, and also as a late phase in the matrix. Rod-shaped inclusions of SiO_2 are rarely found in omphacite grains. The rare inclusions which are present are observed to be parallel to each other, and presumably to the c-axis. Omphacite is occasionally decomposed to a diopside-plagioclase symplectite, whereas phengite is decomposed to a biotite-plagioclase symplectite. Rare late amphibole is also present in the matrix. Garnet is zoned mainly in its regard to grossular, pyrope and almandine distribution, whereas spessartine profile is always flat. The zoning pattern revealed by the compositional step profiles either indicates normal core-to-rim zoning, with slightly increasing pyrope, decreasing almandine (the outermost portions of the rims may show opposite trend) and rather stable grossular, or indicates a somewhat peculiar trend with multiple core domains which do not exhibit any zoning, separated by local pyrope highs (40 mol%) and grossular lows (24 mol%). The cores are characterized by pyrope 37-38 and grossular 25-26 mol%. In the outermost rims both pyrope and grossular slightly decrease. Such composite garnets could have resulted from a coalescence of several single grains. Detailed compositional X-ray mapping coupled with microtomography of several garnet clusters, indeed corroborates the coalescence of several smaller garnets. The anomalous boundaries between the multiple unzoned garnet-core regions are in fact healings between individual garnet grains with former atoll-like textures. This process resulted in pseudooscillatory zoning of garnet. Hence, garnet shows simple zoning with the highest grossular in the cores and the highest pyrope in the rims. However, these changes in chemistry are rather subtle. Clinopyroxene is primarily represented by omphacite with jadeite up to Jd=37 mol%, Ca-Tschermack (Ca-Ts) up to 3.2 mol% and Ca-Eskola (Ca-Es) up to 2.6 mol%. Phengite contains up to 3.33 Si apfu. The peak pressure assemblage consists of Grt-Omph-Ky-Phg-Q-Ru that enables application of the Grt-Omph-Ky-Phg thermobarometry, which was accompanied by the thermodynamic modeling. Both estimates revealed P-T conditions in the range of 28-31 kbar at 770-830°C (Fig. 1).

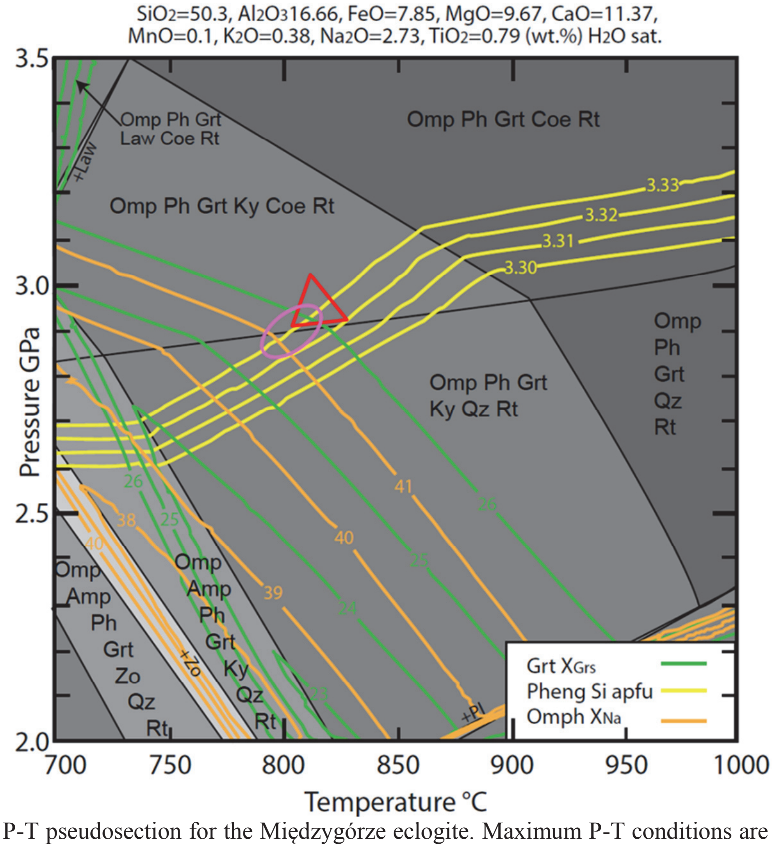

Fig. 1. P-T pseudosection for the Międzygórze eclogite. Maximum P-T conditions are marked by triangle (based on classical thermobarometry) and ellipse (based on isopleths intersection).

Regarding geochronology, first studies of these eclogites were published by Brueckner et al. (1991). They presented Sm-Nd wr-grt-cpx ages obtained for eclogites from different localities, inter alia, from Nowa Wieś, which yielded 337±4 Ma. Subsequently, Bröcker et al. (2009; 2010) reported one Sm-Nd (grt-cpx) age for the Nowa Wieś eclogite (352.2±3.3 Ma) and one concordant zircon U-Pb (SHRIMP) age of 346.3±5.2 Ma for the

Międzygórze eclogite. Walczak (2011; PhD thesis, unpublished) applied both Lu-Hf and Sm-Nd (wr-grt-cpx) techniques to establish eclogite facies timing for the Międygórze and Nowa Wieś eclogites. Results obtained with Sm-Nd technique ranged from 336.2±3.5 Ma to 337.7±2.6 Ma, while Lu-Hf dating gave 346.5±2.4 Ma and 348.1±9.1 Ma for samples from Międzygórze and Nowa Wieś, respectively.

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NIR.info@panalytical.com
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