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

LAMPROPHYRES AND RELATED MAFIC HYPABYSSAL ROCKS: CURRENT PETROLOGICAL ISSUES

Abstracts and field trip guide

RÓŻANKA, SUDETES, POLAND, 14-17 OCTOBER 2010

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XVIIth Meeting of the Petrology Group of the Mineralogical Society of Poland
Różanka, Sudetes, SW Poland, 14-17 October 2010

Dear Colleagues,

The XVIIth Annual Meeting of the Petrology Group of the Mineralogical Society of Poland in 2010 is taking place at Różanka in the Orlica-Śnieżnik Massif, Central Sudetes. The main topic of the meeting concerns the lamprophyres and their current petrological problems but, as is usual, the conference has also a general session covering a wide range of issues in mineralogy, petrology and geochemistry, including interdisciplinary and applied fields.

Lamprophyres are very special rocks that escape even the basic scheme of the classification of igneous rocks. They are distinguished on the basis of their geological form and country rock associations (typically dykes crosscutting granites, less frequently other metamorphic and sedimentary rocks), mineral composition and petrographic features (typically porphyritic texture), and geochemical signatures indicating mantle derivation of their parent magmas. Despite their relative scarcity, lamprophyres are of great interest to petrologists as they carry important information on the structure and composition of the Earth mantle and deep igneous petrogenetic processes. Some types of lamprophyres attract special economic interest, e.g., as diamond-bearing rocks.

The Variscan crystalline basement of the Sudetes in SW Poland contains a number of lamprophyre dyke swarms and, also, dispersed individual lamprophyre dykes. Recent detailed petrological studies on these rocks (see contributions of Marek Awdankiewicz, this volume and references therein) shed light to their petrogenesis and provide important information on intense Variscan magmatism during Carboniferous and Permian times. During the Special Session of the meeting, petrological issues related to the Sudetic lamprophyres and to other occurrences in the Bohemian Massif and adjacent areas, as well as in Altai, Carpathians, Fennsoscandian Shield, Mediterranean region and Spitsbergen, will be discussed, providing an overview of the current understanding of these intriguing rocks.

On behalf of the Board of the Mineralogical Society of Poland and the Organizing Committee of the XVIIth Session of the Petrology Group, I welcome all the participants from Poland and other countries, and wish you scientific benefits and best personal memories from the meeting.

Ryszard Kryza

Minette from Gniewoszów in thin section

Special session

Lamprophyres and related mafic hypabyssal rocks: current petrological issues

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Geochemistry and petrology of alkaline basalt and ultramafic lamprophyre dikes from Lusatia (Lausitz), Germany

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The Lusatian block is dominated by Cadomian basement that largely escaped Variscan metamorphic reworking, whereas the adjacent areas of the Sudetes and the Erzgebirge represent piles of metamorphic nappes. These nappes consist of Cadomian basement and its volcanosedimentary cover, which have been metamorphosed under medium- to high-grade conditions during the Variscan orogeny. Because of the contrasting behavior of Lusatia during the Variscan orogeny, it is possible that the mantle underlying Lusatia had experienced a fundamentally different Variscan geochemical development; in particular it may have escaped metasomatism by agents derived from the subducting slabs. Thus, the comparison of post-Variscan mantle-derived mafic rocks in these areas may allow constraints to be placed on the degree of mantle metasomatism beneath the Sudetes and the Erzgebirge.

Four geochemically distinctive groups of post-Variscan dikes are known from Lusatia: (1) alkaline basalts; (2) amphibole dolerites (spessartites?) (230 Ma); (3) ultramafic lamprophyres (120 Ma), and (4) Tertiary basalts related to the development of the Eger Rift (Kramer 1974, Kramer 1976, Kramer et al. 1977, Renno et al. 2003). Major element geochemistry (high contents of MgO, Fe_2O_3, high Mg#) of the alkaline basalts, the amphibole dolerites, and the ultramafic laprophyres from several locations in Lusatia (e.g., Hochwald, Klunst near Ebersbach, Nucknitz, Pischow) clearly demonstrate the derivation of these rocks from a variably depleted mantle source, whereas incompatible trace elements show crustal signatures. The ultramafic lamprophyre dikes, which occur only in Klunst quarry (and in the former Friedersdorf quarry NW of the Klunst), are characterized by high Th, Cr, Ni, Ba, La, and Sr contents, and a strong enrichment of LREE over HREE, i.e., high La/Yb values. The alkaline basalt shows similar trace and REE pattern, Nb depletion in the mantle normalized trace-element plots, and less pronounced crustal signature. The $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ values of the various dikes fall on a broad mixing array between gabbros that have sampled depleted mantle and typical old crust. The Pb isotopic composition resembles old crust, such as the Saxo-Thuringian crust, whose subduction during the Variscan orogeny is thought to have provided the agents to metasomatize the mantle beneath large parts of the Bohemian Massif. The compositional ranges of ultramafic lamprophyres and alkali basalts may reflect contrasting mantle sources or different degrees of melting of metasomatized mantle. These rocks seem to be derived from melt that involved at least two different mantle components: (i) a mantle source contaminated by crustal material (metasomatized mantle), giving rise to crust-like trace-element patterns and radiogenic isotope systematics, and (ii) a depleted mantle.

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Post-magmatic and weathering-related sheet silicates in the lamprophyres of the Sudetes, SW Poland: preliminary results

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Minettes are a characteristic and widespread type of late Palaeozoic lamprophyre in the Sudetes region (Awdankiewicz 2007). Although fresh rocks composed mainly of phlogopite-biotite and K-feldspar with minor amphiboles (richterite, winchyte) or clinopyroxenes (diopside), are found at several localities, variably altered- and/or weathered samples are very common. Two highly-altered minette specimens were selected for this study. Sample 1 is from a 60 cm thick dyke cutting the Karkonosze granite near Mysłakowice. Sample 2 is from a ca 1 m dyke cutting marbles of the Stronie Formation in the Orlica Massif near Różanka. The samples are grey-brown, locally dark brownish in colour and easily disintegrate into loose fragments variably rich in clay material.

Less-altered fragments were studied in thin section. Clay-size fractions were separated by sedimentation in a glass column on to glass slides and air-dried. Selected samples were treated with Mg^{2+} solution and/or ethylene glycol. X-ray powder diffraction studies involved a SIEMENS D5005 diffractometer (CoKα radiation, accelerating voltage 40 kV, beam current 30 mA). Semi-quantitative analyses of clay minerals were carried out using thermal techniques (DTA, TG, DTG) on a Derivatograph 1500C apparatus.

Petrographic examinations show that secondary sheet silicates mainly replace the primary mafic igneous minerals. The most intense replacement is seen in the dark micas (phlogopite-biotite). The secondary phases form aggregates of small flakes that are brown-stained with minerals of the Fe-hydroxide group. Occasionally, larger chlorite plates can be distinguished. Feldspars are commonly weakly altered.

XRD patterns of clay fractions show that the secondary mineral phases are 10Å-, 14Å- and 29Å-sheet silicates. This indicates the presence of mica-group, chlorite-group and vermiculite-group minerals, as well as corrensite-type mixed-layer silicate. The latter mineral expands on treating with ethylene glycol. The polymineralic composition of the clay fractions is confirmed by the thermal techniques.

The petrographic- and mineralogical studies suggest that the sheet silicates originated by two processes. Post-magmatic hydrothermal processes led to the formation of platy chlorites and secondary mica in some feldspars. However, corrensite, vermiculite and fine-grained chlorite are related to hypergenic alteration processes.

Acknowledgements: The study was supported by Wrocław University grant 2022/W/ING/10/65.

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Petrogenesis of the Late Palaeozoic lamprophyres and related mafic rocks of the Sudetes, SW Poland

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Lamprophyres are mafic, subvolcanic igneous rocks that are commonly found as dykes in a variety of geological and tectonic settings. Currently lamprophyres are considered as one of nine ‘special’ groups of igneous rocks, distinguished by a specific set of geological, geochemical, petrographical and mineralogical features (Rock 1991; Le Maitre et al. 2002). The most characteristic features are the abundance of dark mica and amphibole phenocrysts, the lack of feldspar phenocrysts and marked post-magmatic alteration. The most common lamprophyres – the calc-alkaline (shoshonitic) lamprophyres – comprise minette and kersantite (with dark mica phenocrysts in alkali feldspar and plagioclase-dominated groundmass, respectively) as well as vogesite and spessartite (with amphibole phenocrysts in alkali feldspar and plagioclase-dominated groundmass, respectively).

Lamprophyres attract the attention of petrologists and geologists not only as petrological and mineralogical curiosities, but also for their wider petrological and economic significance. Lamprophyre magmas often represent primitive, mantle-derived melts that carry information on contamination and metasomatic processes in the Earth’s mantle (Rock 1991 and references therein). The primitive lamprophyre magmas may represent mafic end-members that are parental to, and participate in, the formation of other evolved rocks, including voluminous granitoid plutons (e.g. Słaby, Martin 2008). Abundant volatile components and various metals brought by lamprophyre magmas to shallow lithospheric levels contribute to the formation of ore deposits, including gold (Müller, Groves 2000). Lamprophyres, together with kimberlites and lamproites, are also amongst the few rocks that may contain macrodiamonds (De Stefano et al. 2006).

The petrogenesis of calc-alkaline lamprophyres, although relatively well established in major aspects, is far from being fully understood. Though various interpretations have been proposed for individual lamprophyre suites, none of the models seem to have a general, universal application at present. The points of debate include the mantle sources and their melting processes, the genetic relationships between the major lamprophyre types and the relative roles of deep-seated vs. shallow-level processes. Similarly, the possible genetic links between lamprophyres and other associated hypabyssal rocks of andesitic/dioritic, rhyolitic/granitic or trachytic/syenitic composition are commonly not well constrained.

The Sudetes region, at the NE margin of the Bohemian Massif (Fig. 1), may be considered one of the most interesting lamprophyre sub-provinces in the Variscan Belt of Europe. This is because of the abundance of lamprophyres, their wide petrographic variation, good exposure and the presence of unaltered rocks at many localities. This paper presents an overview of the key results of a regional geological and petrological study of the Sudetic lamprophyres and related rocks summarized in Awdankiewicz (2007).

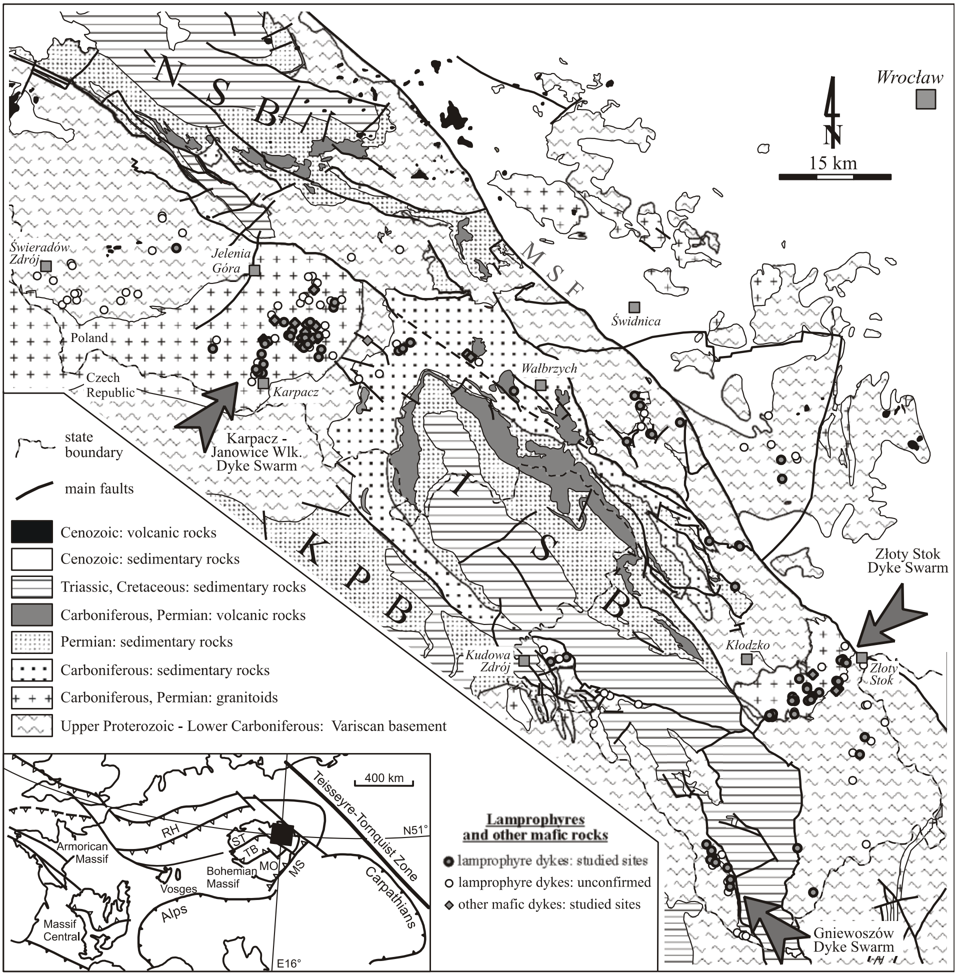

Fig. 1. Geological sketch map of the Lower Silesia region showing the distribution of lamprophyre dykes (modified from Awdankiewicz 2007). MSF – Marginal Sudetic Fault; ISB – Intra-Sudetic Basin; NSB – North-Sudetic Basin; KPB – Karkonosze Piedmont Basin. Inset: location of the main map (black square) within the Variscan Belt of Europe.

The lamprophyric magmatism in the Sudetes occurred in Carboniferous times (Awdankiewicz and Timmerman, unpublished; Awdankiewicz et al. 2010) during a period of post-orogenic extensional tectonism. The lamprophyres, together with associated mafic rocks, were emplaced as dyke swarms and scattered dykes in the crystalline basement rocks, usually within granitoids and commonly adjacent to major crustal dislocations formed during the Variscan orogeny. Dykes within the overlying Permo-Carboniferous molasse deposits are rare. The lamprophyres comprise richterite minettes, minettes, kersantites, vogesites and spessartites (Fig. 2); the other mafic rocks are monzonites, micromonzodiorites and others. Strong and variable chemical zonation of phlogopite-, biotite-, amphibole- and pyroxene phenocrysts is common. Various inclusions such as quartz xenocrysts, granitoid- and schist xenoliths, glomerocrystals and cognate magmatic

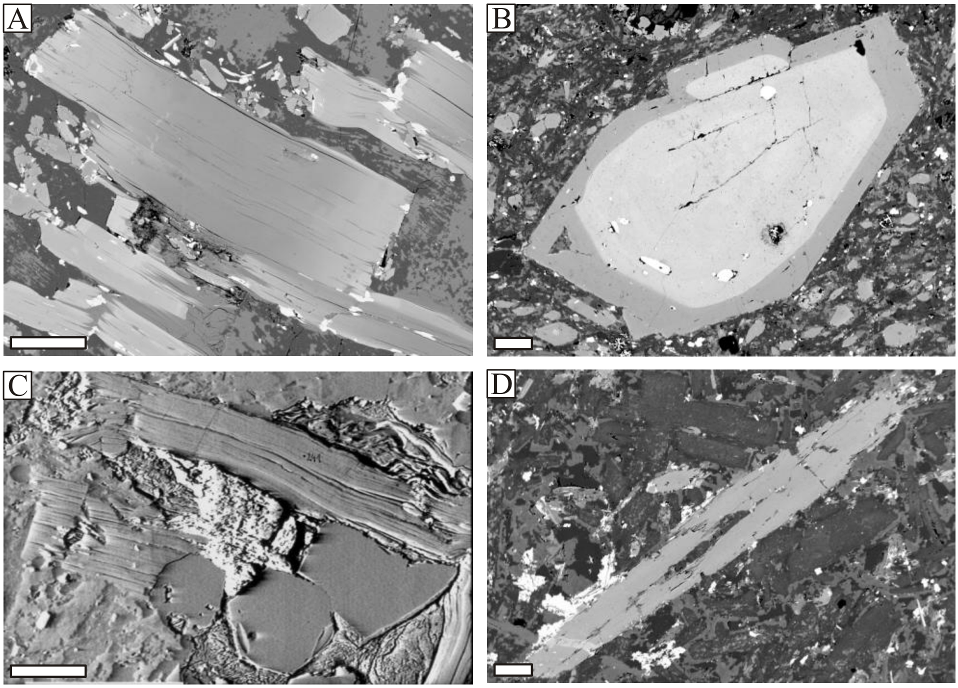

Fig. 2. Selected back-scattered electron images of the lamprophyres from the Sudetes. Scale bar in all images is 100 μm long. A – minette with phenocrysts of dark mica (phlogopite zoned to biotite at rims) in a groundmass mainly of K-feldspar, albite and quartz; Karpacz-Janowice Wlk. Dyke Swarm. B – vogesite with a phenocryst of magnesiohastingsite, showing Mg-enriched margin, in a groundmass of smaller, similar amphiboles and alkali feldspars; Złoty Stok Dyke Swarm. C – kersantite with phenocrysts of biotite and quartz in a groundmass of sericitized plagioclase, chlorite and alkali feldsparł Góry Sowie Block. D – spessartite with kaersutite phenocryst in a groundmass composed mainly of normally zoned plagioclase (labradorite-oligoclase, partly sericitized), alkali feldspars and quartz; Karpacz-Janowice Wlk. Dyke Swarm.

enclaves are found at many localities. The geochemical characteristics of the hypabyssal rocks discussed (Fig. 3) range from ultrapotassic to calc-alkaline and from primitive to evolved (e.g., Mg# = 100Mg/(Mg+Fe) up to ca 80, Cr and Ni up to 700 ppm and 250 ppm, respectively). There is a strong variation in trace element patterns (e.g. from Nb- and Ta-enriched to depleted in these elements) and in the initial isotopic ratios of Nd and Sr (εNd_{300Ma} from +1.9 to –8.3; $^{87}Sr/^{86}Sr_{300Ma}$ from 0.703 to 0.715). It is inferred that the primary lamprophyre magmas originated in the mantle at low degrees of partial melting of phlogopite-, amphibole- and/or garnet-bearing peridotites and, subsequently, underwent variable degrees of differentiation in the lower crust. The regional geochemical, isotopic, petrographic and mineralogical variation indicates that the dyke swarms distinguished represented separate magmatic systems, each characterized by a distinctive mantle source and primary magma composition, and by a specific course of differentiation processes (Fig. 4). The Karpacz-Janowice Wielkie Dyke Swarm, the largest in the region, also shows the widest petrographic variation, comprising nearly all of the rock types mentioned above.

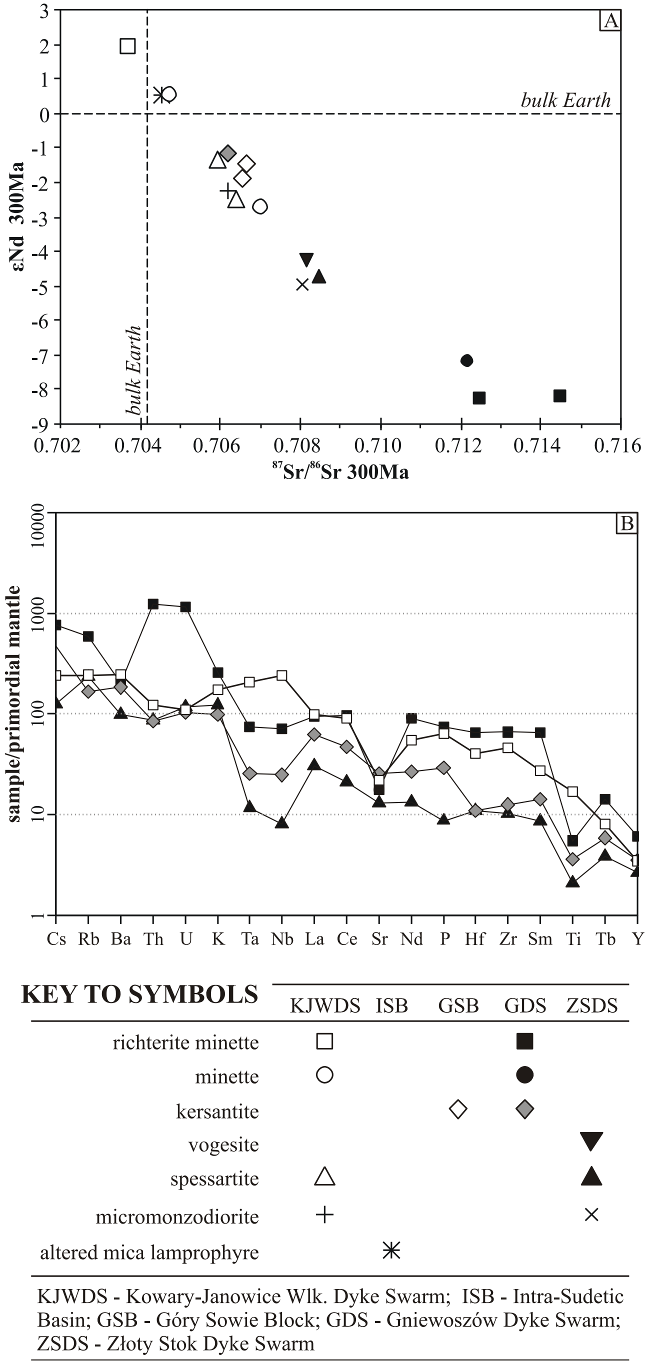

Fig. 3. Selected diagrams illustrating the isotopic and geochemical characteristics of lamprophyres and associated mafic rocks of the Sudetes. A – $^{87}Sr/^{86}Sr$ – εNd plot. B – primordial mantle-normalized (Wood et al. 1979) trace-element patterns of representative samples.

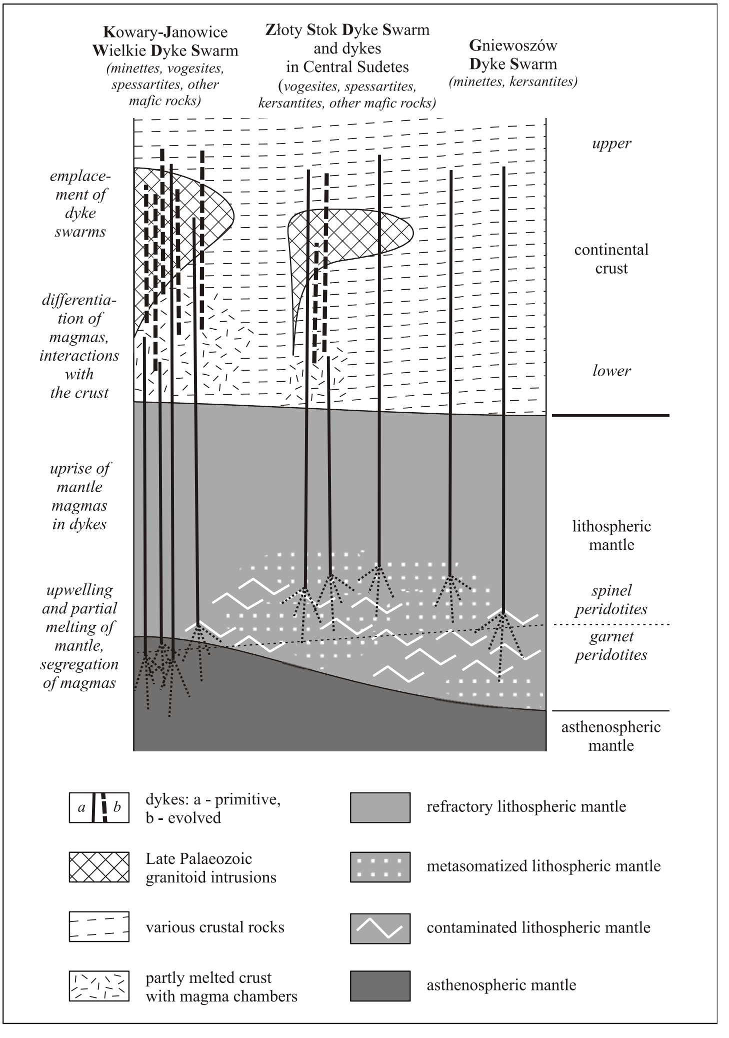

Fig. 4. Tentative petrogenetic model for the late Palaeozoic lamprophyric magmatism in the Sudetes (modified form Awdankiewicz 2007). The lamprophyre melts originated in a heterogeneous upper mantle affected by subduction-related processes. The primitive magmas were either directly emplaced into the shallow crust or variably evolved at lower crustal levels due to magma mixing, contamination and fractional crystallization. Specific source-related and shallow-level processes contributed to the distinctive subvolcanic rock assemblages characteristic of various dykes swarms in the area.

This dyke swarm is distinguished by the strongest influence of asthenospheric-mantle sources, by the dominant role of magma mixing processes during earlier differentiation stages (minettes-vogesites) and by the stronger role of assimilation-fractional crystallization at more advanced stages of differentiation (monzonites-micromonzodiorites). The dyke swarm discussed cuts and postdates the Karkonosze granite, the formation of which involved significant interaction of lamprophyric-, mantle-derived, and silica-rich crustal melts (c.f. Słaby, Martin 2008). On the other hand, the Gniewoszów Dyke Swarm, the smallest in the region and spatially unrelated to granitoids, is petrographically the most monotonous, consisting almost exclusively of richterite minettes and minettes. In this case, the magmas originated from a lithospheric mantle contaminated by crustal rocks and the melts underwent only limited differentiation. The Złoty Stok Dyke Swarm, as well as scattered dykes in the Central Sudetes, show characteristics transitional between the two other dyke swarms. The source of magmas was a lithospheric mantle which contained domains contaminated with crustal materials as well as domains metasomatized by subduction-related fluids. Differentiation processes at shallower lithospheric levels involved variable contributions from the lower crust and resulted in a moderate- to pronounced petrographic- and geochemical variation of the hypabyssal rocks.

The published data on calc-alkaline lamprophyric magmatism and the relationships discussed above provide constraints for more general models of the formation and differentiation of calc-alkaline lamprophyre magmas (Awdankiewicz, 2007). Such magmas typically derive from mantle sources that were affected by subduction of crustal rocks or metasomatized by subduction-related fluids. In post-collisional settings, lamprophyre dyke swarms are emplaced in the upper crust adjacent to significant tectonic discontinuities. The most pronounced geochemical- and petrographic variation in lamprophyre dyke swarms develops at sites of more intense, voluminous and prolonged production of magma in the mantle. This magma feeds long-lived magmatic systems that span extensive sections of the upper mantle and the crust – from the asthenosphere up to the middle/upper crust. In such systems, various combinations of magma mixing and mingling, fractional crystallization and assimilation of crustal components contribute to the diversity of daughter magmas and to the petrographic variation of the dykes. However, restricted and episodic mantle melting inhibits the development of evolving magmatic systems which results in the emplacement of petrologically monotonous dyke swarms weakly overprinted by shallow-level differentiation processes. In the Sudetic dyke swarms, these are the minettes which reveal petrological characteristics dominated by their mantle sources. Vogesites and kersantites have source characteristics variably overprinted by differentiation processes and spessartites represent magmas most strongly modified by shallow-level differentiation processes; these latter may be transitional to and often associated with monzodioritic rocks.

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Alkaline mafic dykes of lamprophyric affinity from Western Pomerania, NW Poland

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Palaeozoic strata in the Pomeranian section of the Trans-European Suture Zone are cut by numerous mafic dykes, revealed during drillings for hydrocarbon prospecting. The dykes are up to 20 m thick and show evident thermal contacts with the surrounding sediments. Most probably, they are Early Carboniferous in age and constituted the westernmost prolongation of Late Devonian/Early Carboniferous magmatism in the East European Platform (Krzemińska et al. 2006). The rocks have been known as diabases since their first description in the early 1970's although their textures range from ophitic through subophitic to intersertal, porphyritic, amygdaloidal and altered vitrophyric, with the most unusual ocelli microstructures set in a fine-grained groundmass. Textural banding in individual dykes clearly suggests several successive injections of magma into expanding fractures.

The primary mineralogy is plagioclase, clinopyroxene, apatite, biotite, ternary feldspar, opaque minerals and, possibly, carbonate. The plagioclase composition ranges from andesine to labradorite. Opaque minerals are primarily titaniferous magnetite and ilmenite. All of the rocks are moderately- to highly altered, rich in chlorite, anatase and carbonates. Mafic minerals were most prone to alteration whereas felsic phases are largely preserved.

Major and trace element geochemistry indicates evolved silica-undersaturated alkali basalts (Mg# from 0.65-0.40; Ni <50 ppm; Cr <20 ppm) which show high La/Yb (~20) and higher REE contents than those in an average OIB. Isotopically, the rocks studied are characterized by almost identical $\varepsilon Nd_{(t)}$ values (from –2.1 to –2.4) and show $^{87}Sr/^{86}Sr$ ratios of 0.7051 in the least altered samples.

The rocks do not fulfill all the criteria for classification as lamprophyres but the mode of their occurrence, mineralogy and chemical composition approximate an alkaline lamprophyre group. We suggest that the dyke rocks derived from a metasomatized mantle source, and that the primary primitive magma subsequently underwent fractional crystallization and mild crustal contamination.

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Amphiboles as indicators of magma origin and fluid evolution

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In this lecture, I will summarize the results obtained on magmatic amphiboles collected from ocean island complexes, intraplate alkaline basalts and subduction-related calc-alkaline volcanic rocks. The ocean island basalt system studied is the Canary archipelago, where amphiboles were investigated in subvolcanic and volcanic rocks on three islands: Fuerteventura, La Palma and La Gomera. The intraplate alkaline basalts erupted in the Carpathian Basin and are thought to have genetic relationships with the Canary Island rocks due to the continuation of the Canary plume beneath the European continent. The asthenospheric upwelling of this plume caused crustal thinning below the Carpathian Basin and resulted in basaltic volcanism. Preceding this volcanism, the mantle area was affected by subduction during the Alpine-Carpathian orogenesis that induced formation of calc-alkaline magmas and a chain of andesitic volcanoes within the Carpathians.

In this paper, I will show the results of combined trace element and isotope studies on amphiboles collected from these complexes. Although the interpretation of geochemical data on amphiboles is not straightforward due to crystal-chemical effects, this mineral group is very useful for several reasons: i) magmatic amphiboles concentrate trace elements relative to other rock-forming magmatic minerals in a way that makes their analysis easier, and ii) amphiboles contain oxygen and hydrogen whose stable isotope compositions ($^{18}O/^{16}O$ and D/H) can provide important constraints on magma origin and fluid influences.

Studies on Canary Island complexes

Fuerteventura (Demény et al. 2004)

The origin of low $\delta^{18}O$ values for ocean island basalts (OIBs) is debated as such low values have been taken as evidence for melt contamination by altered oceanic crust with low $\delta^{18}O$ values or for the involvement of altered and subducted oceanic crust during melting at mantle depths. For the submarine-subaerial Transitional Volcanic Group of Fuerteventura (Canary Islands, Spain) low $\delta^{18}O$ values (4.8±0.3‰) measured for phlogopite and amphibole megacrysts with close-to-HIMU Sr-Nd-Pb isotope characteristics are interpreted to be primary and, on the basis of hydrogen isotope compositions, exclude the influence of crustal assimilation. The model that best describes the chemical and H-O-Sr-Nd-Pb isotope compositions of these minerals favours melting of subducted ocean crust in the OIB source as the cause of low $\delta^{18}O$ values. Low δD values of –115 ± 4‰ have been measured for amphibole megacrysts and are attributed to preceding phlogopite crystallization from a fluid-rich magma. However, phlogopites with close-to-HIMU Sr-Nd-Pb isotope ratios are also depleted in deuterium relative to upper mantle compositions with δD values of –96 ± 1‰, that may be regarded as the pristine H isotope composition characteristic of plume material.

La Palma (Demény et al. 2008)

Chemical and isotopic compositions of amphiboles, biotites, pyroxenes and feldspars from gabbros and basalts of La Palma, Canary Islands were studied in order to determine primary, plume-related compositions and effects of late-stage water/rock interactions. All the studied amphiboles have Sr isotope ratios close to those typical for the mantle, excluding the possibility of significant seawater influence. The pyroxenes and amphiboles also have stable isotope compositions that are typical for mantle derived phases, whereas biotites and feldspars showed signs of interaction with meteoric water. On the basis of the oxygen isotopic compositions, the infiltrating meteoric water derived from precipitation at an approximate elevation of 3500 m a.s.l., indicating that La Palma reached this height when the gabbro complexes were formed. The unaltered hydrogen and oxygen isotope compositions of amphiboles show a trend from normal mantle ranges to –90 ‰ and 5.1 ‰, respectively, values very close to compositions found in other Canary Island complexes by earlier studies, and support the theory that these compositions reflect a plume component originating from the deep Earth, rather than local phenomena.

La Gomera (Demény et al. 2010)

The plutonic rocks of the Basal Complex of La Gomera, Canary Islands, Spain, were studied by means of major- and trace-element contents and by H-O-Sr-Nd isotope compositions in order to distinguish primary magmatic characteristics and late-stage alteration products. Deciphering the effects of alteration allowed us to determine primary, plume-related compositions that indicated D- and ^{18}O-depletion relative to normal upper mantle, supporting the conclusions of earlier studies on the plutonic rocks of Fuerteventura and La Palma. Late-stage alteration that occurred during the formation of the intrusive series was induced by interaction with meteoric water. Inferred isotopic compositions of the meteoric water indicate that the water infiltrated into the rock edifice at a height of about 1500 m above sea level, suggesting the existence of a subaerial volcano which was active during the intrusive activity and that it has been either destroyed or had remained buried by later volcanic and landslide events.

Studies on alkaline basalts of the Carpathian Basin (Demény et al. 2005; 2006)

Major- and trace-element compositions, stable H and O isotope compositions and Fe^{3+} contents of amphibole megacrysts of Plio-Pleistocene alkaline basalts have been investigated to obtain information on the origin of mantle fluids beneath the Carpathian-Pannonian Region. The megacrysts have been regarded as igneous cumulates formed in the mantle and brought to the surface by the basaltic magma. The studied amphiboles have oxygen isotope compositions (5.4±0.2‰, 1σ), supporting their primary mantle origin. Even within the small $\delta^{18}O$ variation observed, correlations with major and trace elements are detected. The negative $\delta^{18}O$-MgO and the positive $\delta^{18}O$-La/Sm(N) correlations are interpreted to have resulted from varying degrees of partial melting. The halogen (F, Cl) contents are very low (< 0.1 wt%), however, a firm negative (F+Cl)-MgO correlation (R^2=0.84) can be related to the Mg-Cl avoidance in the amphibole structure.

The relationships between water contents, H isotope compositions and Fe^{3+} contents of the amphibole megacrysts revealed degassing. The Fe^{3+} (as Fe^{3+}/Fe_{total}) and H_2O contents, as well as the H isotope compositions of the amphiboles differ markedly (27 to 58%, 0.5 to 2.2 wt%, –107 to –15‰, respectively) but indicate systematic variations. The observed trends can be explained either as dehydrogenation or dehydration processes, both of which are coupled to oxidation processes, the latter most probably related to O^{2-} substitution within amphiboles. The dehydrogenation-dehydration models can be used to assess primary compositions of the magmas. Selected undegassed amphibole megacrysts show a wide δD range from –80 to –20‰. The low δD value is characteristic of the normal mantle, whereas the high δD values may indicate the influence of fluids released from subducted oceanic crust. The chemical and isotopic evidence collectively suggest that formation of the amphibole megacrysts is related to fluid metasomatism, whereas direct melt addition is unsignificant.

Detection of plume and slab components in magmatic amphiboles: trace element ratios and stable isotope compositions

As a synthesis of our geochemical studies on magmatic amphiboles, trace-element ratios indicating contribution of subducted slab components (Ce/Pb, Ba/Nb, etc.) and stable isotope compositions will be evaluated using the entire dataset described above. The results have detected a common plume component that was contaminated by slab-derived fluids and melts. A new parameter Pb*/Pb (determined by $Pb/\sqrt{(Ce \cdot Pr)}$), introduced by Marks et al. (2004), characterizes the extent of the Pb anomaly. The usefulness of this parameter and its comparison with other geochemical data will be discussed.

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Lamprophyres in Caledonian basement of SW Spitsbergen

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Spitsbergen is the largest island of the Svalbard archipelago. It is located in the NW part of the Barents Shelf and consists of crystalline basement and sedimentary cover. Basement rocks, Precambrian to Early Silurian in age, were affected by the Caledonian Orogeny. Several terranes of various ages are distinguished there. The unaltered sedimentary cover includes rocks from Silurian to Paleogene.

The samples for this study were collected from the Chambelindalen valley situated in the NW part of Wedel-Jarlsberg Land on the southern coast of Bellsund fjord. This area belongs to the south-western terrane and consists of the following rocks: diamictites, dolostones, various slates, greenstones and greenschists, with several minor intrusions of mafic (diabases) and ultramafic rocks. All of these rocks belong to the Recherchefjorden Sequence.

A few types of lamprophyre intrusions have been distinguished: minette, vogesite and an ultramafic variety, perhaps cortlandite. The ultramafic lamprophyre occurs in the form of a boss-like body up to 200m in diameter and is cut by discrete vogesite dykes up to 0.5m thick. These rocks, together with surrounding slates, were affected by Caledonian metamorphism. To date, they have been described as serpentinites. Minnette type lamprophyre has been found as a W-E trending dyke about 1m thick and extending over 1 km. As it cuts the foliation of the host rocks, it is inferred to be post-metamorphic.

The ultramafic lamprophyre consists mainly of large pyroxene phenocrysts showing different stage of alteration. Magmatic hornblende, with secondary overgrowth of tremolite, and biotite are also present. Serpentine pseudomorphs after olivine are apparent, as well as abundant opaque minerals. Apatite and sphene are accessories. In the groundmass, secondary phases are mostly chlorite, perhaps mixed with serpentine minerals. In the vogesite variety of these rocks, hornblende prevails over pyroxene, biotite is more abundant, and there are no pseudomorphs after olivine.

Minettes are brown porphyric rocks with phlogopite phenocrysts up to 0.5cm in size. Scattered phenocrysts of hornblende are present. The groundmass consists of pyroxene, phlogopite, feldspar and secondary calcite and chlorite. A considerable amount of apatite occurs in the form of acicular- and prismatic micro-phenocrysts.

The main research problem is the relation between the pre- and post-metamorphic types of lamprophyres – their ages, geotectonic setting and the origin of the magmas. The intrusions of ultramafic lamprophyres, vogesites and hornblende-bearing diabases appear to belong to the so-called Appinite Suite.

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Geochemically distinct mantle sources of K-rich lamprophyric magmas from the Moldanubian and adjacent units, Bohemian Massif

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Minettes and kersantites as well as compositionally similar plutonic rocks of Variscan ages from the Bohemian Massif (BM) have primitive mafic compositions and display high LILE/HFSE and Th/Ta or Th/Nb elemental ratios that are broadly assumed to indicate the origin of their parental magmas in mantle sources modified by subduction-related processes. However, there are significant regional differences in their geochemistry.

Typical minettes from the CBPC and Šumava part of the Moldanubian are rich in SiO_2, poor in CaO and Sr, but very high in Rb compared to the world average. Their Rb/Sr is high (about 0.8-1.2) whereas Rb/Cs and K/Rb are relatively low (commonly 7-14 and 100-150, respectively). Their composition is similar to durbachitic plutonic rocks whose voluminous intrusions are very typical of the Moldanubian Zone. Mafic durbachites (amphibole-biotite melasyenites) are currently interpreted as melting products of peridotitic mantle that was strongly modified by interaction with deeply-subducted continental material of granitic composition (Janoušek & Holub 2007). In concert with this interpretation, both minettes and durbachites display negative Eu-anomalies and are isotopically evolved having highly radiogenic Sr (initial $^{87}Sr/^{86}Sr$ = 0.7120-0.7140) and relatively unradiogenic Nd. In contrast to the durbachites with $(^{87}Sr/^{86}Sr)_{338}$ = 0.712-0.713 and εNd = -6.5 to -7.4, minettes are more variable with $(^{87}Sr/^{86}Sr)_{338}$ = 0.707-0.714 and εNd -4.4 to -7.5, perhaps due to their small magma volumes sampling the source heterogeneity.

Kersantites and minettes from the Teplá-Barrandian, and the hidden ultrapotassic Chotělice Intrusive Complex in E Bohemia, have lower Rb/Sr, no or weak Eu anomalies, and are isotopically less evolved with $(^{87}Sr/^{86}Sr)_{338}$ = 0.704-0.706 and εNd = +2.9 to -3.2.

The whole spectrum of Sr and Nd isotopic compositions is similar to that found by Awdankiewicz (2007) for lamprophyres from the Sudetic segment of the BM. The variability of potassic and ultrapotassic magmas from the BM, and the apparent independence of their isotopic compositions of K_2O contents, point to existence of distinctive sources within the heterogeneous Variscan subcontinental lithospheric mantle. Individual lithospheric blocks involved mantle domains with contrasting histories of depletion and diverse episodes of enrichment in incompatible elements.

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Isotopic constraints on the petrogenesis of the Variscan ultrapotassic magmas from the Moldanubian Zone of the Bohemian Massif

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Soon after the Variscan collision, in Viséan times, the Moldanubian Zone of the Bohemian Massif became a scene of vigorous ultrapotassic (UK) igneous activity. As a result, not only did numerous dykes of lamprophyre and melasyenite-melagranite porphyries form, but also sizeable plutons of melanocratic two-pyroxene or amphibole-bearing syenites to melagranites of largely matching mineralogy and chemistry (Holub 1997; Holub et al. 2010). All of the plutons occur in close spatial- and temporal association with bodies of HT-HP, mostly felsic garnet-kyanite granulites enclosing fragments of garnet peridotite and other mantle-derived rocks (Becker 1997, Janoušek et al. 2004, Janoušek & Holub 2007, Kotková 2007 and references therein). Even though the significance of some ages remains to be properly assessed (see discussion in Janoušek et al. 2010a), voluminous UK plutons seem to have intruded in two essentially diachronous pulses: an older, largely late syntectonic and more voluminous durbachite series (~342–339 Ma) and a younger, less deformed, or even post-tectonic, suite of two-pyroxene syenitoids (336–335 Ma) (Holub et al. 1997a, Janoušek & Gerdes 2003, Verner et al. 2008, Kotková et al. 2010, Kusiak et al. 2010). The still scarce ages for the UK dykes fall into the same time interval (Holub et al. 2010).

The durbachite series includes melasyenites (i.e., durbachites *s.s.*) to melagranites with the "wet" assemblage Mg-biotite + actinolitic amphibole as ferromagnesian minerals and commonly with abundant large K-feldspar phenocrysts (Holub 1997). This suite forms many small intrusions and also the large Milevsko (Čertovo břemeno), Knížecí Stolec and Třebíč plutons (Fig. 1). The spatially- and genetically-related biotite–two-pyroxene melasyenites to melagranites (Tábor and Jihlava intrusions) are almost "dry", characterized by a ferromagnesian assemblage Opx + Cpx + Mg-Bt and lack the conspicuous phenocrysts. Late actinolitization and biotitization is common.

The petrogenesis of the two UK plutonic associations remains a matter of debate, even though a likely role for an enriched mantle source has been acknowledged since early on (Holub 1997 and references therein). In order to further constrain the genesis of this conspicuous rock group, we have undertaken a detailed study of their whole-rock geochemistry, including both radiogenic (Sr–Nd) and stable isotopes (O–Li).

In general, the major- and trace-element compositions of both ultrapotassic groups largely overlap, and this is also the case with the isotopic signatures. The Harker plots show a large degree of linearity, with TiO_2, MgO, CaO, FeOt and P_2O_5 forming tight negative and Na_2O positive correlations. The NMORB-normalized spiderplots (Sun & McDonough 1989; Fig. 2a) are characterized by strong enrichments in LILE (Cs, Rb, Ba, K and Li) as well as Pb. Apart from K, high contents of the other two radioactive elements, U and Th, are characteristic. As a result, the ultrapotassic plutons are highly radioactive (Fig. 1). Even the least fractionated types show strong LREE/HREE enrichment in the chondrite-normalized multielement plots (Boynton 1984; Fig. 2b), with marked negative Eu anomalies. There is strong tendency to an overall decrease in total REE contents, and also an increase in La_N/Yb_N and La_N/Sm_N, with decreasing MgO. The most primitive rock types, minettes and durbachites *s.s.*, clearly represent mantle-derived magmas (having high MgO, Mg#, Cr and Ni, and low SiO_2, etc.) offering little scope for modification by more extensive crustal contamination. Instead, they require an anomalous mantle source with significant long-term enrichment in LILE and LREE, or contaminated/invaded by a crust-like component with radiogenic Sr and unradiogenic Nd (Holub 1997, Janoušek et al. 1995, 2000; Wenzel et al. 1997, Gerdes et al. 2000, Janoušek & Holub 2007).

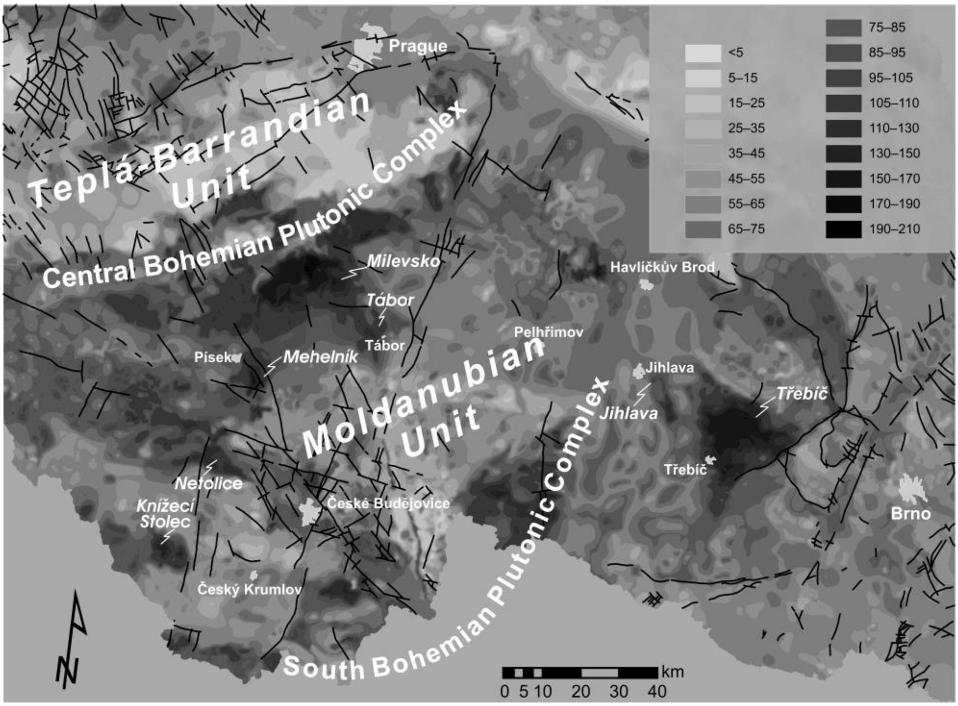

Fig. 1. Radiometric map of the southeastern Bohemian Massif (adopted from the Czech Geological Survey Map Server, *http://www.geology.cz*) with isolines of natural air absorbed dose rate (nGy/h). Labelled are the main bodies of ultrapotassic rocks (durbachite series and melasyenitoids *sensu* Holub 1997) that show very high radioactivity.

The Sr–Nd isotopic compositions of the ultrapotassic rocks are rather variable: initial Sr- isotope ratios and epsilon Nd values resemble mature continental crust ($^{87}Sr/^{86}Sr_{337}$ = 0.710–0.713, εNd_{337} = -6.0 to -7.5). They represent by far the most evolved compositions when compared with somewhat older (~373–354 Ma), voluminous medium-K calc-alkaline- and ~346–347 Ma high-K calc-alkaline intrusions as well as subordinate S-type anatectic granites in the nearby Central Bohemian Plutonic Complex (Holub et al. 1997b, Janoušek et al. 2000, 2010b and references therein). The range of Sr–Nd isotopic signatures of the UK rocks points to a heterogeneous source and/or an important role for open-system interactions such as magma-mixing or crustal assimilation. Rather surprisingly, there is a clear tendency towards *less evolved* (less radiogenic Sr and more radiogenic Nd) compositions with increasing degrees of geochemical fractionation (increasing SiO_2,decreasing MgO, Mg#). This implies that the 'crustal' member was significantly less evolved in terms of its Sr–Nd isotopic signature ($^{87}Sr/^{86}Sr_{337}$ < 0.710,

εNd_{337} > -6) than were some portions of the primary, enriched mantle-derived magma ($^{87}Sr/^{86}Sr_{337}$ ~ 0.713, εNd_{337} ~ -7.5). The required proportions of the acid end member are often high, arguing for magma mixing and ruling out crustal assimilation on thermal/rheological grounds (Holub 1997).

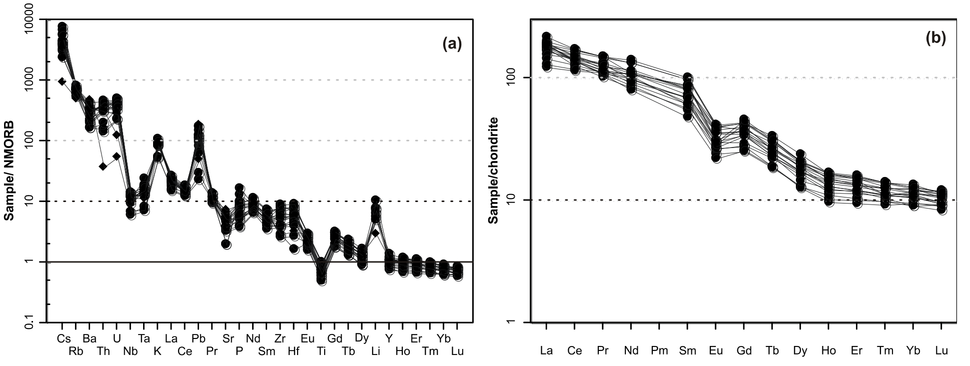

Fig. 2. a) NMORB-normalized (Sun & McDonough 1989) spider plots for the studied ultrapotassic plutonic rocks (durbachite series and melasyenitoids) from the Moldanubian Zone of the Bohemian Massif. b) Chondrite-normalized (Boynton 1984) REE patterns for the same samples.

The stable isotopic compositions of the UK igneous rocks are also variable: $\delta^{7}Li_{SVEC}$ = -3.4 to +1.5 ‰, $\delta^{18}O_{SMOW}$ = +6.7 to +10.8 ‰. All lithologies, including the apparently mantle-derived members, show $\delta^{7}Li$ values significantly lower than the NMORB average of +3.5 ‰ (Tomascak 2004) and $\delta^{18}O$ values higher than the NMORB average of +5.7 ‰ (Harmon & Hoefs 1995). Highly mafic UK rocks from the Šumava Mts. have $\delta^{7}Li$ (-1.9 to -3.4 ‰) significantly lower even than average upper continental crust with $\delta^{7}Li$ ~ 0 ‰ (Teng et al. 2004).

Taken together, the observed geochemical- and Sr–Nd–Li–O isotopic variability can be explained by a two-step model: 1) interaction of the mantle with subducted crustal rocks (mainly felsic metaigneous rocks converted to HP granulites) having $^{87}Sr/^{86}Sr_{337}$ > 0.713, εNd_{337} < -7.5, $\delta^{7}Li$ < -3 ‰ and $\delta^{18}O$ < +7 ‰, and/or with fluids and melts derived during eclogite-/HP granulite-facies metamorphism at the Variscan collision climax (Janoušek & Holub 2007) followed by 2) magma mixing of primary magmas derived from such an anomalous mantle source with anatectic melts generated at the base of the former igneous arc ($^{87}Sr/^{86}Sr_{337}$ < 0.710, εNd_{337} > -6, $\delta^{7}Li$ > +2 ‰ and $\delta^{18}O$ > +10 ‰).

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Pre-Mesozoic lamprophyres and lamproites of the Bohemian Massif (Czech Republic, Poland, Germany, Austria)

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Introduction

Mantle-derived mafic dykes such as lamprophyres typically occur as late- to post-collisional intrusive rocks across of the European Variscan belt. They are widespread in the crystalline areas of the Bohemian Massif where the term ‘lamprophyre’ was introduced by Gümbel in 1874.

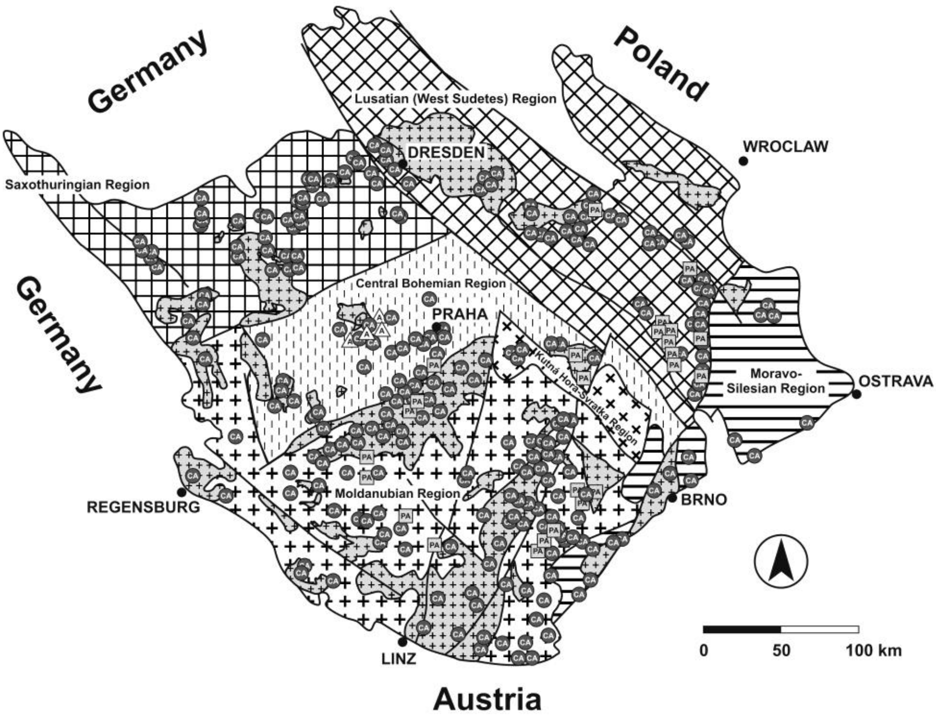

Fig. 1. Main distribution of pre-Mesozoic lamprophyres, lamproites and associated dyke intrusions in the Bohemian Massif. Legend: CA – calc-alkaline (shoshonitic) intrusions: minette, kersantite, spessartite, microdiorite, microsyenite; A – alkaline intrusions: camptonite, small stocks of alkaline diorites, meladiorites to hornblendites; PA – peralkaline (lamproitic) intrusions: ‘peralkaline minette to microgranite’. Regional geological subdivision of the Bohemian Massif with location of main granitoid intrusions (grey colour with crosses) was modified according to Zoubek (1985).

The lamprophyres are often accompanied by contemporaneous dyke rocks petrographically ranging from microgabbro/microdiorite to microgranite that may bepetrogenetically related to the lamprophyres through differentiation processes (e.g., magma mixing, fractional crystallization). This contribution briefly summarizes and interprets the most important published results on pre-Mesozoic orogenic lamprophyres (i.e., lamprophyres *sensu stricto*; see the paper by Krmíček and Krmíčková in this volume) and associated dykes of the Moravo–Silesian, Moldanubian, Kutná Hora–Svratka, Central Bohemian, Saxothuringian and Lusatian Region (Fig. 1). Within the individual regions, the state of lamprophyre research differs. The term 'pre-Mesozoic' covers both Variscan lamprophyres and possible pre-Variscan dykes. Moreover, important occurrences of Variscan orogenic lamproites (i.e., SiO_2-rich peralkaline dykes with specific mineralogy) are also mentioned in the text. This rock-type cropping out in the Bohemian Massif remains poorly recognised in terms of the modern understanding of lamproites.

The Moravo–Silesian Region

Occurrences of lamprophyric dykes along the eastern margin of the Bohemian Massif have been described from almost all basic pre-Mesozoic geological units of the Moravo–Silesian Region. They are known both from the Austrian and the Czech part of the Thaya Massif and from the adjacent Moravicum; they have been described in the Brno Massif, in the basal Devonian clastics, in the Vrbno Group of the Silesicum and in the Drahany Culm and the Nizký Jeseník Culm basins (see Krmíček 2010 and references therein). Semilamprophyre dykes (varieties with colour index less than 25 – see Wimmenauer 1973) occur especially in the Upper Silesian molasse basin and in the Kraków volcanic area. It is very interesting to note that within the widespread carbonate outcrops of the Moravian Karst (tens of kilometres), we do not know any lamprophyre occurrences. With regard to this fact, the author speculates about the idea that unmetamorphosed carbonates of higher thickness could represent some kind of geochemical/structural barrier for the intruding thin lamprophyric dykes. However, this is not valid for much more compact marbles which are cut by lamprophyric dykes in different localities of the Bohemian Massif (e.g., in the Moldanubian Region).

The age of lamprophyres in the Moravo–Silesian Region is Variscan. Assumptions about Cadomian ages (e.g., in the Thaya Massif) were excluded by Krmíček and Přichystal (2005). The results of radiometric dating (both published and unpublished) indicate a long period of lamprophyre emplacement with the presence of more 'lamprophyric events' in the area. The south-eastern sector of the Bohemian Massif (Austrian part) is locally transected by two generations of lamprophyric dykes that post-date internal Variscan deformation of the variably metamorphosed constituent nappe units (Neubauer et al. 2003). ESE trending dykes of the first generation are locally weakly foliated, however their 323±3 Ma Ar–Ar biotite plateau age is considered to be sufficiently representative. Biotite concentrates from the younger, unfoliated dyke generation (dominantly NNE trending) yielded Ar–Ar plateau ages of 315–306 Ma (Neubauer et al. 2003). Lamprophyres from the Czech part of the Moravo–Silesian region partly belong to the generations distinguished by Neubauer et al. (2003) or are younger. The youngest known Variscan lamprophyre intrusive event of the Bohemian Massif is uppermost Lower Permian (based on unpublished Ar–Ar ages) and was discovered by the author in the Drahany Culm foreland basin at the village of Rozstání–Baldovec. At the north-eastern margin of the Czech part of the Moravo–Silesian Region, a widespread dyke swarm was described in the vicinity of Janov (Silesia) by Dvořák and Přichystal (1982). The swarm continues to the Polish side near the village of Jarnoltówek. Hornblende K–Ar analysis of this dyke swarm gave an age of 302±5 Ma (Dvořák and Přichystal 1982). The dykes from

Janov are mineralogically variable with abundant quartz xenocrysts. They can be considered as a product of mixing between mantle-derived and crustal melts. The importance of lamprophyre-type magmatism during the final stages of the Variscan orogeny is also documented by the presence of post-tectonic I-type granitoid plutons of mixed origin. Geochemical data have been interpreted as evidence for interaction between lamprophyric and granitic melts during the formation of the Žulová or Žulová–Strzelin Massif, respectively (Krmíček 2007, 2010). Lamprophyres at the eastern margin of the Bohemian Massif are important tracers of magmatic activity connected with the final stages of the Variscan orogeny.

The Moldanubian Region (Moldanubicum)

The Moldanubian Region is well known for its common occurrences of lamprophyres (minettes, kersantites, spessartites) and related rocks (microsyenites, microdiorites, microgabbros); they occur in a large area across the geological boundaries (e.g. Becke 1883; Foullon 1883; Němec 1970, 1975a). Beside that, we can consider the most basic members of the durbachite series as plutonic equivalents of Lower Carboniferous mica lamprophyres. This was recently proven by the experimental studies of Parat et al. (2010). Moreover, unique post-collisional peralkaline dyke rocks characterized by the mineral assemblage K-rich amphibole + microcline ± phlogopite ± aegirine ± quartz were encountered in this region, especially in the vicinity of Raabs in Austria and Třebíč in the Czech Republic (Hackl and Waldmann 1935; Thiele 1960; Němec 1987a,b, 1988). The dykes were originally described by Hackl and Waldman (1935) and given local names such as "raabsite", "thuresite" and "karlsteinite". Despite their previous petrogenetic classification as intrusions of the "minette differentiation series" (peralkaline minette, microsyenite and microgranite, respectively; e.g., Němec 1987a,b), the dykes show mineralogical and geochemical features typical for SiO_2-rich lamproites of the Mediterranean-type (Krmíček 2010). However, the Mediterranean-type lamproites are of Cenozoic age whereas, in the Bohemian massif, the dykes with lamproitic affinity intruded at ~330 Ma (Krmíček et al. 2008; Awdankiewicz et al. 2009). Orogenic lamproites are generated by partial melting of lithospheric (subduction-modified) mantle rocks that were depleted in basaltic components and subsequently enriched in mantle-incompatible elements (K, Rb, U, Th). Additionally, mixing with components originating from the lowest lithospheric – upper asthenospheric mantle (HFSE, especially Ti, Zr) is commonly recognized. The lamproitic magmatism of the Bohemian Massif is very probably related to slab-break off and ascending of hot asthenospheric mantle. Asthenospheric upwelling may have also contributed to uplift and rapid Variscan erosion of the Moldanubian zone. The most lamproitic Variscan intrusion of the Bohemian Massif is represented by a Ba-Ti-Zr-rich peralkaline, perpotassic and ultrapotassic dyke from Šebkovice (Fig. 2; Krmíček et al. 2010). The Šebkovice dyke is also the first recognized Variscan lamproite in the whole Variscan orogenic belt in terms of the modern understanding of lamproites. The Šebkovice lamproite (~NE–SW trending) cross-cuts sillimanite–biotite paragneisses of the Moldanubian middle-crustal Variegated (Drosendorf) Unit near the western margin of the Třebíč Massif. Krmíček et al. (2010) described the complex petrography and crystal chemistry of its minerals, which include several compositionally unusual species such as potassic analogues of richerite and magnesio-arfvedsonite, Fe-rich microcline, Ba-bearing titanite, baotite (ideal formula $Ba_4Ti_8Si_4O_{28}Cl$), henrymeyerite (ideal formula $Ba(Ti_7Fe^{2+})O_{16}$), benitoite (ideal formula $BaTiSi_3O_9$) and bazirite ($BaZrSi_3O_9$).

The Kutná Hora–Svratka Region

Within this smallest region of the Bohemian Massif, the lamprophyres are known only from the Kutná Hora Unit. Losert (1962) instructively described a specific type of amygdaloidal infilling in the mica lamprophyres from the Kutná Hora ore mines. The amygdales are formed by polycrystalline aggregates of felsic minerals that are tangentially rimmed by flakes of mafic mica (Fig. 3). These are considered to be segregation vesicles (cf. Mauger 1988; Holub 2003). Their origin involves exsolution of an immiscible volatile-rich fluid phase and vesiculation due to decompression of the rising melt, or due to its cooling and crystallization. Subsequently, the vesicles are partly or completely refilled with felsic residual melt infiltrating from the surrounding interstitial spaces. As was documented for lamprophyres from this area, the segregation vesicles could even originate at depths of a few kilometers below the surface. The presence of segregation vesicles is a characteristic feature of volatile-rich lamprophyres. Segregation vesicles with mica or amphibole rims were observed by the author in dykes from all regions of the Bohemian Massif.

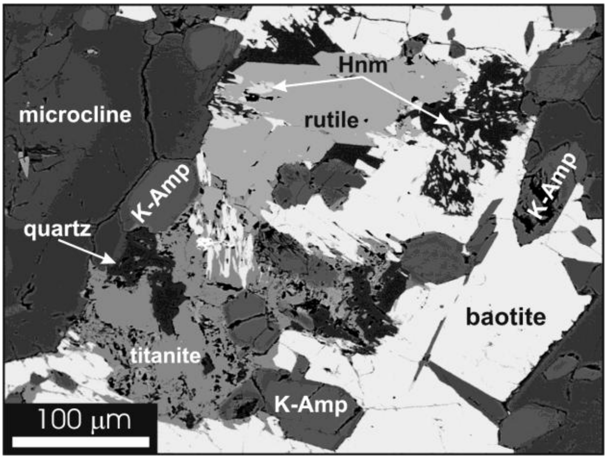

Fig. 2. An example of the interstitial filling in the most lamproitic Variscan intrusion of the Bohemian Massif (the Šebkovice dyke; backscattered electron image): interstitial baotite enclosing euhedral K-amphiboles (K-Amp) is partially replaced by anhedral titanite, quartz, rutile and rare henrymeyerite (Hnm).

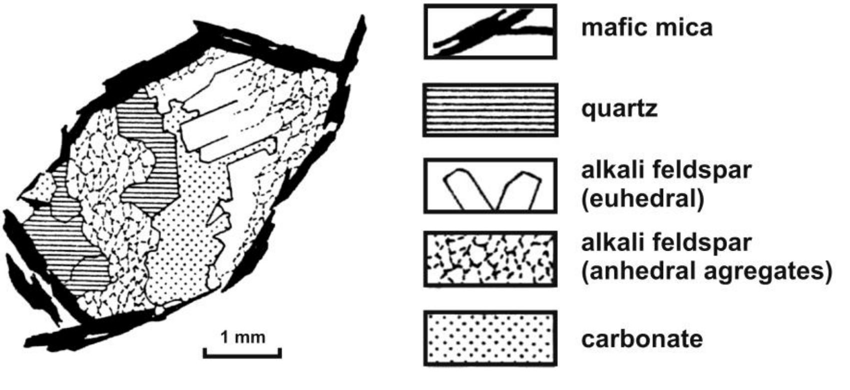

Fig. 3. Typical segregation vesicle in lamprophyre (schematic drawing modified according Losert 1962).

The Central Bohemian Region (Bohemicum)
Generally, in this region we can observe numerous dyke generations with Variscan ages. Moreover, some authors speculate about pre-Variscan generations. Lamprophyres in the Bohemicum cross-cut the rock sequences of the Barrandian Proterozoic and Paleozoic and its equivalents in the Železné hory Mts, the metamorphic "islets" enclosed in the Central Bohemian Pluton, the Domažlice Unit and the Hlinsko Proterozoic and Paleozoic (see Krmíček 2010 and references therein).

Probably the first lamprophyre recognized in the Bohemian Massif was recorded by J. Barrande in his personal notes from 1865; he found a minette dyke in the village of Černošice. Recent study of the Černošice dyke, which cross-cuts the Ordovician sequences of the Prague Basin, revealed than the dyke contains xenoliths of individual tentaculite shells (Krmíček 2010). As xenoliths and xenocrysts usually occur in lamprophyres, such minette-enclosed tentaculite shells are a real curiosity on a worldwide basis (Fig. 4).

Very specific are the 'appinite texture type' intrusions located in the north-western part of the Barrandian Proterozoic, between Rakovník and Plasy (Dolejš 1995). They include occurrences of camptonites, spessartites and microdiorites genetically related to small alkaline stocks of pyroxene–amphibole diorites, meladiories and hornbledites (e.g., Krmíček et al. 2009). The internal variability of this group probably resulted from fractionation under changing H_2O activities.

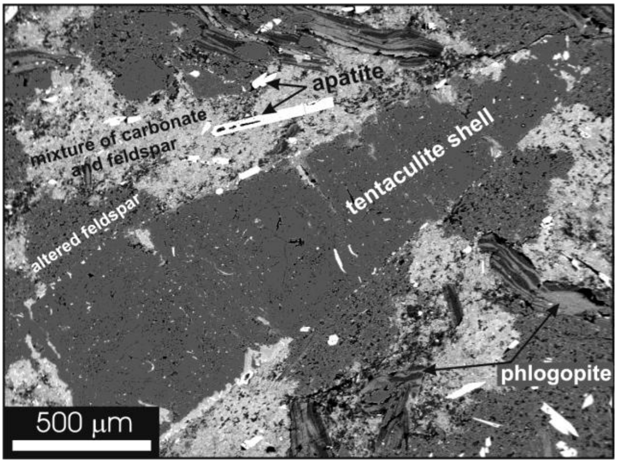

Fig. 4. Probably the first lamprophyre recognized in the Bohemian Massif. Minette dyke contains unique xenoliths of individual tentaculite shells (the Černošice dyke; backscattered electron image).

Ultrapotassic dykes (lamprophyres to lamproites) represent an important Variscan generation; they crop out near the Bohemicum/Moldanubicum boundary in the Central Bohemian Pluton and in the the Železné hory (Nasavrky) Pluton. The Bohemicum/Moldanubicum boundary is a significant Variscan tectonic zone separating two different regional units of the Bohemian Massif. According to Finger et al. (2007) the Bohemicum may have functioned as a rigid backstop along which earlier subducted HP–HT rocks (Gföhl Unit) were steeply exhumed into the Moldanubian middle crust. The geochemical signature of the mentioned ultrapotassic dykes suggests formation in a metasomatised mantle that was contaminated by deeply subducted, evolved continental crust (Krmíček et al. 2008). The observed enrichments in Cs, Th, U, K and Pb manifest the genetic link to exhumed Moldanubian granulites which are depleted in just these same elements (cf. Janoušek and Holub 2007). Moreover, an important feature of the ultrapotassic dykes cropping out near the Bohemicum/Moldanubicum boundary is the presence of negative Eu anomalies (Eu/Eu* = ~0.6). This could be an additional argument for contamination of their mantle source with evolved crust material. Significant feldspar fractionation in these dykes is rather improbable.

The Saxothuringian Region (Saxothuringicum)

The Saxothuringian lamprophyres are well known, especially because of the mining history of this area. The dykes are spatially (and maybe genetically) associated with significant ore districts (e.g., Seifert and Sandmann 2006; Štemprok et al. 2008). The results of Ar–Ar step-heating dating of mineral separates from a series of lamprophyre dykes in the Saxothuringian Region features Viséan–Namurian (334–323 Ma) and Stephanian–early Permian (297–295 Ma) crystallization ages (von Seckendorff et al. 2004). This is indicative of magma generation over a long period of 30 Ma. Kersantite from the lamprophyre type area of Gümbel (1874) yielded a 297±2 Ma age and belongs to the younger intrusive event. Generally, the lamprophyric dykes from this area lack negative Eu anomalies (von Seckendorff et al. 2004).

Coexistence of mantle-derived and crust-derived melts in the Saxothuringian Region is suggested by occurrences of hybrid intrusions of amphibole–biotite gabbros to monzonites that are traditionally labelled redwitzites. Redwitzites have been originally regarded as the plutonic equivalents of lamprophyres (Willmann 1920). The age range of the redwitzites (325–322 Ma; Siebel et al. 2003) overlaps the emplacement ages of the older granites in the Fichtelgebirge–Erzgebirge area. New geochemical modelling results suggest that the chemical and mineralogical variability of redwitzites can be explained by mixing between mafic and felsic magmas with minor fractional crystallization. The parental mafic magma was probably produced by melting of a metasomatised mantle, the melts being close to lamprophyre or alkali basalt composition (Kovaříková et al. 2010).

The Lusatian (West Sudetes) Region (Lugicum)

Lamprophyre occurrences at the northern margin of the Bohemian Massif (the territory of the Czech Republic, Germany and Poland) have been reported from almost all basic pre-Mesozoic geological units (see Krmíček 2010 and references therein). The exceptions are the Zábřeh and Nové Město units as well as the Krkonoše Piedmont and Orlice basins. Awdankiewicz (2007) provided extensive information on the dykes situated on the Polish part. The majority of the dykes in the Lusatian Region have supposedly late-Variscan ages. This was supported by Ar–Ar step-heating dating of micas and U–Pb SHRIMP dating of zircons that revealed ages between 330 and 300 Ma (Awdankiewicz et al. 2009). Former speculations about Cadomian ages for the lamprophyres (but not for 'dolerites') in the Lusatian Pluton were refuted by Krmíček (2010).

The distribution of dykes is not uniform. They are especially abundant near regionally important Variscan tectonic zones, e.g., in the presumed equivalent of the Bohemicum/Moldanubicum boundary in the Orlice–Sněžník (Śnieżnik) Unit or in the Staré Město Suture Zone (Silesicum/Lugicum boundary). It is very probable that Variscan orogenic collapse in the Lusatian Region resulted in significant lithosphere detachment accompanied by upwelling of hot asthenospheric mantle. This is manifested by a great abundance of peralkaline (lamproitic) dykes (e.g., Waldmann 1935; Pauk 1958; Němec 1975b; Wierzchołowski 2003) as well as by the occurrence of post-collisional massifs of mixed origin. Interaction with a mantle melt of lamprophyric composition was described in the Krkonoše–Jizera Massif (Słaby a Martin 2008), in the Strzegom–Sobótka Massif (Domańska-Siuda and Słaby 2005) and in the Kłodzko–Złoty Stok Massif (Lorenc 1994).

Conclusions

The majority of lamprophyres of the Bohemian Massif are Variscan in age. The distribution of lamprophyres within single regions of the Bohemian Massif is not uniform. They show obvious connections to important sutures and tectonic zones. The temporal range of lamprophyric magmatic activity is at least 60 Ma (334–274 Ma). Two peaks of lamprophyric magmatism occurred close to the Lower/Upper Carboniferous and Upper Carboniferous/Permian boundary. The youngest lamprophyre intrusive event (uppermost Lower Permian) occurred in the eastern orogenic foreland, in the Moravo–Silesian Region. A comparison with Variscan orogenic collapse models (Praeg 2004) suggests that the timing of 'lamprophyric events' corresponds to collapse of the central internides followed by reorientation and foreland-directed migration of the collapse. The dykes show typical geochemical signatures similar to those of lamprophyres from the Western European Variscan orogen which are generally linked to metasomatised mantle sources (both LILE enrichment and abundant transition metals; see Turpin et al. 1988). This confirms the presence of a subduction-related, metasomatised mantle across the Variscan orogenic belt and also explains why their subduction-related geochemical character (e.g., Ta-Nb-Ti anomaly, Pb anomaly etc.) does not agree with their predominant post-collisional intra-orogenic occurrence (Fig. 5). Another important demonstration of Variscan, mantle-derived magmatic activity of lamprophyric composition is the occurrence of hybrid intrusions of durbachites (Moldanubicum) and redwitzites (Saxothuringicum). Mantle (lamprophyric) magmatism also played an important role during the genesis of post-collisional granitic intrusions at the NE margin of the Bohemian Massif, such as those of Krkonoše–Jizera, Strzegom–Sobótka, Kłodzko–Złoty Stok or Žulová–Strzelin massifs.

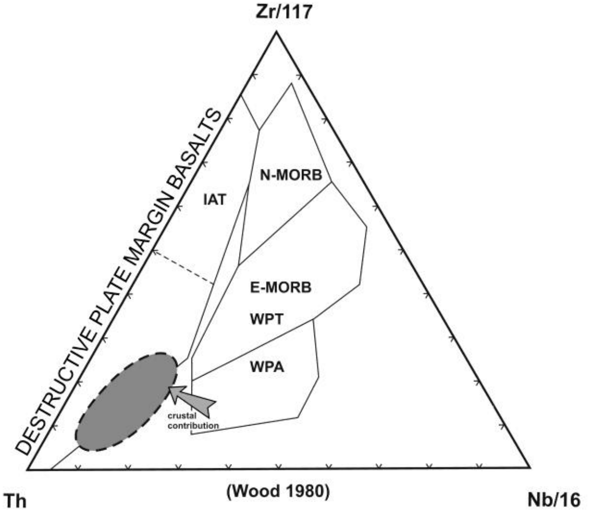

Fig. 5. Orogenic lamprophyres in the Th-Zr-Nb discrimination diagram. A contribution from previous subduction events is clearly visible (relative Th enrichment and Nb depletion).6

Additionally, unique, post-collisional peralkaline dyke rocks characterized by the mineral assemblage K-rich amphibole – microcline ± phlogopite ± aegirine ± quartz have been found, especially in the Moldanubian and in the Lusatian regions. Despite their previous petrogenetic classification as intrusions of the 'minette differentiation series', these dykes show mineralogical and geochemical features similar to those of SiO_2-rich orogenic lamproites.

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Recent view on a definition and classification of lamprophyres

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Before the second half of the 20th century, the lamprophyres were considered more as a petrographic curiosity than as an important mantle-derived rock group. The term "**lamprophyre**" (from the Greek words "lampros" and "porphyros" = glistening porphyry) had been introduced by Gümbel (1874, p.36) for Permo–Carboniferous dark-coloured dyke rocks from the Bohemian Massif characterized by glistening phenocrysts of mafic mica embedded in a feldspar groundmass (**minette** and **kersantite**). To these, Rosenbuch (1887, p.308) analogically added the rocks with phenocrysts of lustrous cleavage amphibole (**vogesite** and **camptonite)** from which **spessartite** was subsequently distinguished. Thus, at the end of the 19th century, lamprophyres comprised a simple group of five original types. During the 20th century, petrologists enlarged this ill-understood group by incorporating different rocks containing mafic phenocrysts such as kimberlites, lamproites, nepheline-, leucite- and melilite-bearing rocks. This resulted in a single large supergroup of polygenetic rocks termed the "**lamprophyre clan**" characterised by five principal branches further subdivided into 21 rock types by name (Rock 1991). The fact that the proposed concept was rejected by involved scientists (e.g., Mitchell 1994; Woolley et al. 1996) subsequently led to subdivision of the supergroup into individual rock groups by the IUGS Subcommission (Le Maitre et al. 2002). Unfortunately, the Subcommission placed foid-bearing and foid-free lamprophyres into one group in spite of the conclusion of numerous scientist (e.g., Wimmenauer 1973; Mitchell 1994 and references therein) that "lamprophyres" with abundant feldspathoids were ordinary alkaline basalts that had crystallized under volatile-rich conditions. The last step in the present understanding of lamprophyres was taken by Le Bas (2007). After more then one hundred years evolution of the family of lamprophyres, Le Bas (2007) restored Rosenbuch's initial concept based on the five original lamprophyre types (Table 1).

	predominant mafic mineral with OH group		
predominant felsic mineral	phlogopite/biotite	magnesiohastingsite + others Ca amphiboles	kaersutite
potassium feldspar	**minette**	**vogesite**	**----**
plagioclase	**kersantite**	**spessartite**	**camptonite**

Table 1. Proposed principal subdivision of the lamprophyres. Modified according to Le Bas (2007).

Without doubt, the restored concept is a return to the roots that gives back meaning to the term "lamprophyre". As **true lamprophyres,** we can now recognize the following types (end-members): minette, kersantite, vogesite, spessartite and partly camptonite (*sensu* Rosenbuch 1887). These types could be termed **orogenic lamprophyres** because they are genetically linked with individual stages of orogenic development as is especially evident across the European Variscan belt where all five types occur.

This recent understanding of lamprophyres provides a sound basis for rejecting these rocks as a variable group of polygenetic origin. As orogenic lamprophyres share some similar mineralogical and geochemical features, we may propose the following modified **definition** (for details see Krmíček 2010): "Lamprophyres are a genetically significant group of predominantly dyke rocks with porphyric- (prevailing), equigranular- or poikilitic texture, characterized by the presence of euhedral hydrous mafic minerals such as calcic amphibole and/or Al-undepleted mafic mica. Feldspars, the most abundant felsic minerals, are restricted to the groundmass. Their principal geochemical features, i.e., high contents of mantle-compatible elements (e.g., Mg, Ni, Cr) and mantle values of ε_{Nd}, together with high contents of mantle-incompatible elements (alkalis, volatiles, Ba, Zr, Th, U, P, LREE) and crustal $^{87}Sr/^{86}Sr$ values, distinguish the lamprophyres from the common plutonic or volcanic rocks".

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SHRIMP zircon study of a spessartite dyke from the Kłodzko-Złoty Stok granite, Chwalisław (Sudetes)

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The Kłodzko-Złoty Stok (KZS) granite massif is composed mostly of metaluminous and transition to peraluminous igneous rocks rich in biotite and hornblende, with abundant mafic enclaves and rare xenoliths of metamorphic rocks. The major rock types are granodiorite and quartz monzonite, with lesser amounts of quartz diorite, monzonite, diorite and syenite. Due to subsequent magmatism, melanocratic (spessartite and vogesite) and leucocratic (pegmatite, etc.) dykes and quartz veins were formed (Wierzchołowski 1977). These dykes crosscut the granitoids, and also their metasedimentary country rocks, mainly in the eastern and southern parts of the KZS (Wojciechowska 1975). The geochemical and petrographic characteristics of lamprophyres from the Sudetes, including the Złoty Stok Dyke Swarm, have been described in detail by Awdankiewicz (2007).

The spessartite sample selected for zircon geochronology was collected from an abandoned granite quarry on the road from Mąkolno to Chwalisław. A spessartite dyke ca. 1m thick cuts granodiorite. The spessartite is dark grey and fine-grained, with elongated plagioclase and hornblende needles defining a slightly fluidal texture. Biotite phenocrysts are partly chloritized. Augite porphyrocrysts are distinctly sericitized and albitized. The crystalline groundmass contains accessory minerals such as quartz, titanite, Ti-magnetite, calcite and zircon. Secondary calcite veinlets also are present.

Sixteen zircon grains (100-250 μm diameter) were analyzed. There are three distinct populations, all with typical igneous zoning. The grains are mostly euhedral, some are subrounded. Most grains have strong CL bright and dark oscillatory zoning. All the Pb/U dates are Paleozoic (~570–325 Ma) except for one (~2.2 Ga - the oldest zircon). One population of 6 crystals yielded Neoproterozoic, fairly concordant weighted mean $^{206}Pb/^{238}U$ age of 566.3±6.4 Ma. A second population of 6 zircons had a Paleozoic mean $^{206}Pb/^{238}U$ age of 333.1±3.1 Ma, which we interpret as the intrusion age of the spessartite dyke.

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Lamprophyres from the Żeleźniak igneous rock suites (Kaczawa Mountains) – geochemistry, petrography and preliminary SHRIMP zircon ages

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The Żeleźniak igneous rock suite (ZI) is composed of sub-alkaline and alkaline rocks and minor granites of Late Carboniferous age. Multiple episodes of hydrothermal activity related to this post-collisional potassic magmatism are responsible for the formation of auriferous sulfide-bearing quartz ± carbonates veins of the Radzimowice Au-As-Cu deposit (Mikulski 2005). Hypabyssal lamprophyre dykes represent a third group of ZI igneous rocks (Mikulski 2005). Among these, 2 types of kersantites, both with porphyritic textures, are recognized. The first type shows typical coarse-grained textures, with biotite phenocrysts (<0.5 mm) and phenocrysts of secondary minerals after olivine in a crystalline groundmass containing plagioclase (andesine), quartz, biotite and carbonates. The second type is characterized by fine-grained porphyritic textures and carbonate, chalcedony and chlorite pseudomorphically replacing primary olivine in a fine-grained groundmass consisting of sericitized plagioclase and biotite. The second type of lamprophyre is strongly affected by carbonatization and arsenic contents are highly elevated (0.05-0.1 wt% As) due to hydrothermal processes. On a K_2O-MgO diagram, they plot in the fields of kersantite and spessartite. The lamprophyres have low SiO_2 (44-47 wt%), high Na_2O (up to 1.6 wt%), and high MgO (8-10 wt%) contents. Their K_2O/Na_2O ranges between 1.1-1.9. They have relatively high LILE, low LREE and low HFSE contents. These rocks have Mg# from 77-79 and high concentrations of mantle-compatible trace-elements.

Previous SHRIMP zircon dating of monzogranites and rhyodacites from the ZI indicated that the main igneous event was at ca 315 Ma (Machowiak et al. 2008). We have dated zircon from one lamprophyre dyke. Eleven zircon grains (50-100 μm diameter), representing a mixed population of euhedral to subrounded short-prismatic to normal prismatic crystals, were analyzed. The internal structure of the crystals was varied, ranging from CL-dark unzoned to moderate CL, simple igneous zoning. All dated grains had igneous zoning. All the dates are Paleozoic (~565–305 Ma) and the analyses are mostly concordant within error. Seven analyses define the youngest group, five of which have the same ^{206}Pb-^{238}U within error, giving a weighted mean age of 312 ± 4 Ma (95% conf.). Given the range in zircon morphologies and measured dates, it is possible that even the youngest grains are contaminants from the country rock. The mean age of ~312 Ma is therefore a maximum for the age for the lamprophyre dyke; it might well be younger.

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The role of magma mixing in the origin of minette lamprophyres: examples from Mediterranean Tertiary volcanic provinces

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Our understanding of the petrogenesis of lamprophyres is perhaps the poorest of any igneous rock group. The main reason for this is the confusion that reigns concerning their relationships with other rock and magma types. Systematic studies and groupings of lamprophyres were pioneered mostly by Rock (1977, 1983, 1991), who produced a series of publications aimed mostly at classifying the rocks and understanding their interrelationships. The interest has recently been revived with several publications which further classify lamprophyres and constrain their origin (Prelevic et al. 2004, Tappe et al. 2005, Scarrow et al. 2009). Generally, lamprophyres are melanocratic hypabyssal igneous rocks with microporphyritic textures carrying hydrous mafic phenocrysts (Wimmenauer 1973, Rock 1991, Woolley et al. 1996). Feldspars and other felsic minerals are restricted to the groundmass. The calcalkaline or shoshonitic lamprophyres received their group name from the common association with calcalkaline granitic rocks (Rock 1977), and consist entirely of feldspar-bearing lamprophyres, excluding glassy, carbonate- and feldspathoid-dominated lamprophyres. Many are minettes, a name for which Mitchell (1994) proposed a redefinition to restrict its use to rocks associated with calcalkaline volcanism and plutonism. The high modal phenocryst content, reverse zonation and resorption of macrocrysts in the most calcalkaline lamprophyres indicate a complex origin including crystal fractionation, hybridization and possibly accumulation of phenocrysts.

The idea that calcalkaline lamprophyres might originate by mixing of lamproites and crustally derived silicic melts was first proposed by Rock (1983, 1991), based on geochemical relationships. He suggested that within orogens, especially in areas of active granitoid plutonism, mantle-derived lamproite melts find passage through the continental crust very difficult and are usually thoroughly modified by the uptake of crustal components, resulting in the formation of minette melts. There are several examples of intimate associations between calcalkaline lamprophyres and granitoid rocks reported from different orogenic areas: appinites from the Caledonian orogeny (Fowler and Henney, 1996), vaugnerites from the Hercynian orogeny (Sabatier 1991, Gerdes et al. 2000, Ferré and Leake 2001). The appinites are considered to represent plutonic spessartites and vogesites, whereas vaugnerites correspond to kersantites and minettes (Rock 1991). The occurrence of lamproites in Hercynian orogenic belts has been only recently reported (Buzzi et al. 2010), confirming previous indications of the lamproitic affinity of lamprophyres (Sabatier 1991, Ferré and Leake 2001) indicated by good correlations between MgO and K2O, high K2O/Na2O and low Al2O3 of the most primitive rocks.

The Mediterranean part of Alpine–Himalaya belt is another orogenic area where an intimate association between calcalkaline lamprophyres and granitoid rocks have been reported (Venturelli et al. 1984, Prelevic et al. 2004). The aim of my presentation will be twofold:

i) I will concentrate on the geochemical features, and the origin, of Mediterranean lamproites. They are ultrapotassic rocks, strongly enriched in incompatible trace elements, but with a high Mg number and high compatible trace-element contents characteristic of mantle-derived melts (Mitchell and Bergman 1991, Prelevic et al. 2008). They occur in Spain, Italy, Serbia, Macedonia and Turkey, generally associated with intra-continental tectonic settings or post-orogenic collapse, post-dating convergent tectonics and active margin processes. In this setting, lamproites may be associated with calcalkaline lamprophyres and calcalkaline silicic magmatism, so that the mixing of melts with contrasting compositions might be expected in this environment.

ii) I will focus on the genetic relationships between minette and lamproitic melts. Using examples of Mediterranean lamprophyres from N. Italy and Serbia, I will demonstrate the significance of the high reactivity and potential for magma mixing of lamproitic melts. The lamprophyres in these areas are hybrid rocks showing many types of reaction textures and indicating incomplete equilibration. These observations provide evidence for an important role of magma mixing in the origin of calcalkaline lamprophyres. Finally, I will present a comprehensive model by which lamproitic melts are involved in the origin of calcalkaline lamprophyres in general.

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Contributions to the metallogenetic importance of lamprophyres – examples from polymetallic Au-, Sn-W-Mo-Li-In-, As-Zn-Sn-Cu-In-Pb-Ag- / Ag-Sb-, and U-ore clusters

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Based on a worldwide database of lamprophyres, N.M.S. Rock (1991, p. 155) noted that "...lamprophyres are a missing element in the traditional 'granites + mineralization' maxim which should no longer be ignored; it may be at least as reasonable to attribute certain components of mineralizing fluids to deep, mantle-derived, lamprophyric melts as to shallower granitic magmatism ...".

A possible connection between Au mineralization and lampropyhric intrusions has been discussed over many years (e.g., McLennan 1915; cf. Rock and Groves 1988a,b; cf. Rock 1991, Kerrich and Wyman 1994, Müller and Groves 1995, Kelley and Ludington 2002; cf. Seifert 2007, Geißler and Seifert 2009). Lamprophyres in Au-bearing districts show Archean to Tertiary ages (e.g., ca 2.6-2.7 Ga: Eastern Goldfields and Murchison provinces in the Yilgarn Block (Western Australia), Superior Province; 1.8 Ga: Woods Point (Australia); 400 Ma: Caledonides (Scotland), Pine Creek (Australia); Permo-Carboniferous: Bohemian Massif (Czech Republic, Germany); Jurassic-Tertiary: Sierra Nevada and Klamath Mountains (CA), Rossland (BC), Kreuzeck Mountains/Alps (Austria), Cripple Creek (CO), Porgera (P.N.G.). In agreement with Rock (1991, and references therein), it can be postulated that the gold-lamprophyre association represents a deep-seated magmatism which can transport Au ligandes from Au-rich sources in the deeper mantle. These volatile-enriched, hot lamprophyric melts then undergo an extensive crustal interaction, generating felsic magmas and releasing their Au into hydrothermal systems. The persistent and widespread association in both space and time between hydrothermal Au(-polymetallic) mineralization and lamprophyric intrusions (especially calc-alkaline lamprophyres) is an important metallogenetic factor for genetic models of post-magmatic Au mineralization and for their exploration in different geotectonic environments [continental arc, oceanic (island) arc, post-collisional orogenic, within plate (anorogenic intracontinental rifting)].

In the European Variscides and other orogenic belts (e.g., Central Asian Orogenic Belt, Russian Far East, Kokanee Range/BC), several large Sn(-W-Mo), Ag-base metal, and uranium ore fields are reported in the literature where lamprophyric- and dioritic magmatism is commonly interposed in time before or between granitoid magmatism and later ore deposition (e.g., Rock 1991, Beaudoin et al. 1999, Borisenko et. al. 2006, Pavlova and Borisenko 2009, Pavlova et al. 2009, Seifert 2008a,b, 2009, Seifert and Baumann 1994, Štemprok and Seifert, this volume; and references therein).

Because of a mining history that spans almost 800 years and because of the occurrence there of thousands of old Sn, Ag, Cu, As, Co, and Fe mines and some large Sn-W-Mo-Li, W-Mo, Sn-Zn-In, Ag-Pb-Zn-In, U(-Ag), fluorite, and barite mines (cf. Baumann et al. 2000, and references therein), the Erzgebirge-Vogtland area is one of the key localities to study the genesis and genetic relationships of different pneumatolytic and hydrothermal mineralization stages and late-Variscan magmatic events in the Internal Variscides (Seifert 2007, 2008a, and references therein). The traditional model for the genesis of the late-Variscan ore deposition favored a crustal-derived, syn- to late-collision granite magmatism (Tischendorf, 1988 and references therein). An alternative model suggests a mantle-related magmatic event and associated high-temperature fluids as a source of Sn-W-Mo, Ag-base metal and rare metal-bearing mineralization (Seifert 2008a, 2009). The metallogenetic importance of post-collisional lamprophyres (especially type LD2) is indicated by their high volatile concentrations (CO_2, H_2O^+, F, Cl, S, P_2O_5) and relationships to A-type rhyolitic intrusions and late-Variscan Sn-W-Mo-Li-In / As-Sn-Zn-Cu-In-Pb and Ag-Sb / U ore deposition (Seifert 2008a). Additionally, they frequently occur in districts exhibiting intensive and economically important late-Variscan mineralization processes. The post-magmatic origin of rare metal-bearing Sn-W-Mo and Ag-base metal mineralizations, and their genetic link, is indicated by mineralogical, geochemical, isotopic, fluid inclusion, age relationship and structural features (cf. Seifert 2007, 2008a). Because of this fact, and because of the close spatial and time relationship to post-collisional lamprophyric and rhyolitic intrusions, mantle-derived fluids associated with the Permo-Carboniferous bimodal magmatism are likely to have been the main source of economic Sn-W-Mo and Ag-base metal mineralization systems (Seifert 2008a, 2009). Important for any future exploration for Permo-Carboniferous rare metal-bearing Sn-W-Mo and Ag-base metal and U deposits in the Erzgebirge, and possibly also for other metallogenetic provinces, are the following: (1) Late-Variscan ore deposits are spatially associated with intrusion centres of Permo-Carboniferous post-collisional mafic and rhyolitic (sub)volcanic magmatism along deep-rooted NW-SE fault zones, especially at their intersections with major NE-SW and E-W structural zones. (2) Post-collisional lamprophyric and small Li-F granite intrusions and associated explosive breccia pipes, and microgranitic/rhyolitic stocks and dikes which postdate late-collisional ‘type Eibenstock’ granite complexes, are an important positive metallogenetic factor for the exploration of Sn-W-Mo deposits (e.g., Krupka, Pobershau-Marienberg, Gottesberg-Mühlleithen). (3) The occurrence of LD2-type lamprophyres is a significant indicator of high economic potential for Ag- and In-rich polymetallic base-metal sulfide ore deposits (e.g., Freiberg, Marienberg, Annaberg). (4) CO_2-rich LD2-type lamprophyres could be important in the formation of uranium veins in the Erzgebirge, and in other districts in the Variscan orogen (e.g., Ronneburg, Příbram-South), since CO_2-rich high-temperature fluids associated with the intrusion of CO_2-rich lamprophyric melts are easily capable of leaching the high-U, late-collisional granites and of transporting high U concentrations in fissure-controlled hydrothermal systems. It cannot be excluded that the U-rich fluids of the first U mineralization stage (“uqk” ore-type) in the Erzgebirge are directly linked to younger post-collisional lamprophyric intrusions and associated mantle-derived U-rich fluids (Seifert, 2008b) as in the Streltsovsky and Elkon ore fields in the Transbaikal-South Yakut uranium superprovince where large U deposits are linked with basaltic and felsic (bimodal) subvolcanic intrusions (Aleshin et al. 2008, Veličkin et al. 2008).

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Lamprophyres of the Western Carpathian crystalline complexes; petrology and geochemistry

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In the Western Carpathians, two basic types of lamprophyre rocks of different age and composition have been reported. The first type is represented by calc-alkaline lamprophyres (pre-Alpine age) occurring in the crystalline complex of the Western Carpathians and the second type by Cretaceous alkaline basalts/lamprophyres. Since the rocks of the second type have not been clearly identified as alkaline lamprophyres (Dostál – Owen 1988), attention is focused here on the first type.

The Pre-Carboniferous complexes of the Western Carpathians comprise calc-alkaline lamprophyres, a rare and exotic rock type. They occur in the Tatric unit (core mountains) and rarely in the Veporic unit (Slavošovce; Mišík 1953, Hovorka 1967). In the past, they were given different names (diorite porphyrite, spessartite, kersantite, odinite, cuzelite etc.). In the Tatric unit, there are several occurrences of lamprophyre rocks. In the Nízke Tatry Mts (Ďumbier zone), they occur north of Železné (Koutek 1931) in the surroundings of Jarabá (Kamenický 1961, Krist 1967) on the southern slopes of Veľký Gápel Hill (Turan 1961). In the northern part of the Považský Inovec Mts, lamprophyres occur in several localities in mica schists and gneisses in the crystalline complex (Hovorka 1960). In the Suchý Mts, they can be found on the south-eastern slope of the Okrúhly vrch Hill (Ivanov - Kamenický 1957). The most examined are lamprophyres from the Malá Fatra Mts (Spišiak – Hovorka 1998). Here, they occur on the floor of a productive quarry at Dubná skala in Variscan tonalite.

The geological occurrences of the lamprophyre rocks are similar. They are dyke bodies that are as much as several metres thick. They mostly occur in mica schists, gneisses or Variscan tonalites. Rare dykes contain xenoliths of the host rocks – mainly tonalite. The dyke rocks are dark-green, massive, in most cases aphanitic, with uniform, granular, non-porphyritic textures. Amygdaloidal types are common as well. Most phenocrysts (approx. 5 mm) are clinopyroxenes, amphiboles, biotites, quartzes and plagioclases. In many cases, porphyritic minerals are altered. The matrix is composed mainly of chlorite, fine needles of plagioclase, apatite, zircon and ore minerals. Secondary minerals are chlorite, epidote, clinozoisite, sericite, limonite and hematite.

Based on their chemical composition, the lamprophyres of the Western Carpathian crystalline complexes can be classified as calc-alkaline lamprophyres (Rock 1987) – kersantite, spessartite. The age of the lamprophyre rocks has not been precisely determined, but we assume it to be pre-Alpine and the dykes to be connected with the termination of Variscan magmatism.

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The association of lamprophyric intrusions and rare-metal mineralization

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We searched for occurrences of lamprophyres in about 300 hundred literature sources on granite-related tin, tungsten and molybdenum ore deposits in orogenic settings. In contrast to abundant lamprophyres in gold-bearing districts, which range in age from Archean to Tertiary times (Rock 1991), calc-alkaline and alkaline lamprophyres in rare metal districts are exclusively Phanerozoic in age. We noted 56 cases of such occurrences, all in the northern hemisphere. They are reported in the Mesozoic provinces of Russia, namely in the Maritime region, Chukotka, Yakutia-Kolyma, and Transbaikalia and the Tienshan of Russia and Uzbekistan, and in the Paleozoic provinces of Central Europe (Krušné hory and Erzgebirge in the Czech Republic and Germany) and Western Europe (Central France and SW England) - see Štemprok (1995) and Seifert (2008). In Northern America, they are in the Paleozoic province of the Appalachians of Canada and in the Cenozoic provinces of the North American Cordilerra of the USA and Canada (Rock 1991). The literature data are, however, hampered by the fact that the petrographic nature of lamprophyres is not always definitively identified and that the limits of rare metal ore districts are conceived differently by various authors. Lamprophyres are reported in rare metal districts with Sn, W, Mo, Li and Ta mineralization which have dispersed ore minerals in granites or in veins and stockworks as well as in altered rocks such as greisens, skarns, tourmaline, chlorite and/or sulphidic ore types. If petrographically described, the lamprophyres are classified as kersantites, minettes, vogesites, spessartites, or with camptonites or monchiquites. Their occurrences were noted mostly in the supra-intrusion zone of complex granitic bodies as pre-granitic dykes (L1 lamprophyres), but some had intruded later than the earliest granitoids (L2 lamprophyres). Some lamprophyres proved to be syn-ore, more rarely post-ore in time of their origin (L3 lamprophyres, e.g., in the Erzgebirge, Seifert 2008). In some rare cases, lamprophyres occur jointly with cupolas of highly evolved lithium albite granites. The occurrences of lamprophyres commonly trespass the limits of rare metal districts and may be connected with lineaments intersecting various major lithologies in an orogene. Most lamprophyres are spatially associated with dominant felsic dykes (aplites, pegmatites, microgranites, rhyolites) or intermediate dykes (diorites or granodiorites) or with mafic dykes (gabbros, diabases, and dolerites). The genesis of lamprophyres is apparently unrelated to the source of granitoid magmas which formed ore bearing fluids, but is connected with mafic magmas generated in metasomatized upper mantle. Lamprophyric dykes in rare-metal bearing districts share common geochemical characteristics with some highly evolved granitoids such as the enrichment in potassium and fluorine and abundance of some lithophile elements such as Li, Rb and Cs. This may suggest that the sources of mafic and felsic magmas were affected by the same volatiles derived either from the deep mantle or from subducted lithospheric slabs. The lamprophyres in rare-metal districts testify to the accessibility of the upper crust to the mantle products at the time of ore mineralization. These may also include some ore elements scavenged by the fluids of various origin from the mantle.

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Petrology of lamprophyres of Chuya complex (SE Altai)

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The SE Altai and NW Mongolia are recognized as a large ore district in which Ag-Sb, Sb-Hg, Ni-Co-Bi-Ag-U, Cu-Co-As and Mo-W ore systems are known. This ore district is spatially associated with a large area of Early Mesozoic magmatism represented by dike swarms of alkaline mafic rocks (minette, kersantite, bostonite), dolerites, small intrusions of syenite and granosyenite, and later leucogranite intrusions and ongonite dykes. Lamprophyre and dolerite dike swarms are of special interest in this district. The numerous dike swarms occur in two local areas: the South Chuya area where they are associated with Ni-Co-As, U, Cu-Hg-Sb (Ag, Hg-tetrahedrite with hematite in barite-carbonate veins) mineralization and the Yustid area in which Ag-Sb and Ni-Co-As mineralization predominates. The dike swarms localized in the Cambrian and Ordovician metamorphic host rocks in the South Chuya area and in the Middle-Upper Devonian black shale in the Yustid area are two components of the Chuya complex.

Multi-element diagrams for the lamprophyres from different areas are practically identical, displaying the same geochemical features. All lamprophyres are depleted in Sr and HFSE, and have a high La/Y. Spider diagrams of all lamprophyres are absolutely congruent and have steep slopes. At the same time, there are some systematic distinctions between the compositions of dikes from different areas. South Chuya dikes contain more SiO_2 but less CaO, P_2O_5, Fe_2O_3 and MgO. On Harker diagrams, the compositions of dikes from different areas belong to different clusters.

Main minerals of lamprophyres are phlogopite, pyroxene (in Yustyd dikes only), potassium feldspar and calcite. However, the proportions of these minerals vary greatly and, as a result, contents of SiO_2, for example, vary also. All rocks are porphyritic. Phenocrysts in the dykes of both areas comprise phlogopite and another mineral wholly replaced by carbonate with an ore rim. A difference between the dikes is that most of the South Chuya dikes show spherulitic structure and some of Yustyd dikes are characterized by ocelli structure. The spherulites are composed of thin intergrowing blades of feldspar and phlogopite. In some samples a carbonate-ore cement is clearly visible. Ocelli in the South Chuya dikes are separated by tangential blades of phlogopite. In different dikes, large crystals of calcite and feldspar in different proportions or fine-grained masses of these minerals with phlogopite phenocrysts can be seen. Some authors have suggested that the ocelli are a result of leucite replacement. But CIPW modeling shows that in some lamprophyres with ocelli, leucite could not appear.

Melt-, crystal-fluid and fluid inclusions occur in the minerals of the lamprophyre dykes (apatite, zircon, pyroxene and quartz xenocrysts). Gas phases of nitrogen (N2 100 mol %) or nitrogen-carbon dioxide (N_2 91.7-99.8 and CO_2 8.3-0.2 mol %) composition were established in the minerals from the lamprophyres of the South Chuya area. Anhydrite crystals, characteristic inclusions in the lamprophyres of this area, suggest an oxidized magmatic fluid. A gas phase of nitrogen-methane (N_2 97.3 and CH_4 2.7 mol %) composition, and a lack of anhydrite inclusions in the minerals from the lamprophyres of the Yustid area, point to a reduced magmatic fluid. Thus, it is concluded that the lamprophyres of Chuya complex had a single parental source. Differences in rock composition and in the compositions of inclusions can be explained as due to the influence of the host rocks and multi-stage crystallization.

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Can mica thermobarometry be effectively applied to mica from shoshonitic lamprophyres? The case of the Palaeoproterozoic lamprophyres of the Fennoscandian Shield

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Lamprophyres are mafic to ultramafic dyke rocks, which commonly contain mica (biotite or phlogopite) as both a matrix phase and as macrocrysts. Shoshonitic (calc-alkaline) lamprophyres are mafic lamprophyres containing feldspar as a matrix phase, which occur in late- to post-orogenic tectonic settings. Precise knowledge of the pressures of both magma generation and dyke emplacement can be of great benefit for developing models of orogenic evolution. Righter and Carmichael (1996) developed a thermobarometer for use on mica from shoshonitic lamprophyres, based on mineral-melt partitioning of Ba and Ti. Although this was said to be applicable up to pressures of 3 GPa, their calibration experiments were invariably performed at low pressures and the results extrapolated to higher pressures. As a result, despite the potential of this thermobarometer, it has been only sparsely used. We have analysed macrocrystic and matrix mica from Palaeoproterozoic shoshonitic lamprophyre dykes in the Fennoscandian Shield and discuss the validity of the thermobarometric data.

Macrocrysts occur as compositionally zoned, often castellated pseudohexagonal laths, typically around 1 mm but up to 1 cm across. Many macrocrysts contain crystallographically oriented, needle-shaped inclusions of titanite. Matrix grains are less than 0.2 mm across, inclusion-free and typically strongly pleochroic.

Macrocrysts typically exhibit core-to-rim zoning, appearing progressively brighter towards the rims in BSE images. The biotite cores (Mg# 65-75) are relatively enriched in Si, K and F. A gradational increase outwards in Mg#, Ti, Al and Ba is observed near the rims. Matrix phlogopite (Mg# > 75) has similar composition to the inclusion-free outer rims of the macrocrysts, with strong enrichment in both Ti and Ba.

Thermobarometric results from the matrix micas indicate crystallisation at temperatures of 1100-1150ºC at 0.2-0.3 GPa, corresponding to an emplacement depth of 7-10 km. This is in accordance with previous depth/exhumation estimates from this area (Niiranen 2000). Thermobarometric results from the macrocrysts form a well-defined trend toward T = 1200ºC and P = 2.5 GPa. Still higher values (up to P = 4.5 GPa) were obtained from the core zones of many macrocrysts, however these data become scattered such that a distinct path of decompression is no longer discernable. This uncertainty could reflect disequilibrium between xenocrystic cores and the lamprophyric melt. However, as the thermobarometer has not been experimentally calibrated at such high pressures, the scatter is potentially due to problems with the extrapolation. We suggest that our data shows the potential of the mica thermobarometer, but further experiments at high pressures are needed for calibration.

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The Chełmiec subvolvanic intrusion (Intra-Sudetic Basin, SW Poland): preliminary SHRIMP zircon age

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The Chełmiec intrusion belongs to the Permo-Carboniferous succession of the Intra-Sudetic Basin, a late Palaeozoic intramontane trough in the eastern part of the Variscan Belt of Europe. The intrusion is a prominent rhyodacite laccolith in a group of acidic, subvolcanic- to extrusive igneous bodies set within coal-bearing Carboniferous strata. The emplacement age of these acidic rocks has been indirectly determined as Late Carboniferous (Westphalian), but a Permian age has also been suggested (discussion in Grocholski 1965, and Awdankiewicz 1999).

The sample for our SHRIMP study was collected from the central part of the Chełmiec laccolith, ca 1 km south of the top of Mt. Chełmiec. The sample is a porphyrytic rhyodacite with phenocrysts of altered feldspars and biotite in a microcrystalline groundmass. Zircons were separated using standard methods and were analyzed at the Beijing SHRIMP Centre, the People's Republic of China.

In transmitted light, the zircons are colourless and transparent, mostly euhedral, rarely subhedral and irregular. Their habit varies from short- to normal- to long-prismatic (elongation between 1 and 5); the latter are often broken. Many crystals are cracked and display local rusty colouration. Small prismatic- and elongated, oval-shaped inclusions parallel to the C-axis are fairly common. In CL images, most of the crystals are distinctly zoned, with recurrent thin magmatic-type zonation. Some crystals display sectoral, hour-glass zonation. No distinc cores are discernable.

The zircons contain rather low amounts of U (126–679 ppm, max. 814 ppm), and Th (42–230 ppm, max. 996 ppm). The $^{206}Pb/^{238}U$ ages vary between 299±7 and 327±7Ma, with the weighted mean of 308±3 Ma (2σ). Excluding the youngest points with relatively high common lead Pb_c, the mean age for 13 points is 310±4 Ma (2σ). The mean Concordia age for these 13 points is exactly the same. This age is interpreted as corresponding to the main magmatic crystallization event in the Chełmiec intrusion. The older concordant age of 327±7 Ma may reflect an earlier magmatic stage, whereas the younger ages around 300 Ma apparently indicate subsequent disturbaces and Pb loss.

The magmatic age of 310±4 Ma for the Chełmiec intrusion corresponds to the middle part of the Late Carboniferous (Westphalian/Moscovian).

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The Góry Suche Rhyolitic Tuffs (Intra-Sudetic Basin, SW Poland): preliminary SHRIMP zircon age

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The Góry Suche Rhyolitic Tuffs represent a regional stratigraphic marker in the Lower Permian Volcanic Complex of the Intra-Sudetic Basin, a late Palaeozoic intermontane trough in the eastern part of the Variscan Belt of Europe. The Lower Permian Volcanic Complex is assigned to the Lower Autunian. However, the volcanic rocks of the Complex had not been dated using isotopic methods (Awdankiewicz 1999 and references therein).

The sample for this study comes from an abandoned quarry near the village of Grzędy. This rock is a slightly welded ignimbrite, related to a major eruption which ejected a hundred(?) cubic kilometers of tephra that spread across the basin as ash-flows. The sample consists mainly of devitrified glass shards and broken quartz- and feldspar phenocrysts with minor pumice and lithic fragments. Zircons were separated using standard methods and were analyzed at the Beijing SHRIMP Centre, the People's Republic of China.

In transmitted light, the vast majority of the zircons are euhedral, normal- to short-prismatic, transparent and colourless. Very few grains are subrounded, nearly isometric, and a few crystals are broken. A number of grains are moderately cracked and spotty, rusty colouration is rather common.

All of the 21 analyses show low $206Pb_c$ contents, between 0.09 and 0.76%. Significant differences in CL images of the zircons correlate with their age groupings. The oldest ages of ~ 570, 515 and 440 Ma come mostly from CL-bright interiors of euhedral crystals with distinct magmatc zonation and relatively low U and Th contents. Another group of five zircons with a mean Concordia age of 343±7 Ma (2σ) comprises relatively CL-bright (low to moderate U and Th concentrations) and zoned grains. The largest population of ten analysed zircons has a mean Concordia age of 300±4 Ma (2σ); these are typically CL-darker (moderate- to high U and Th contents) and indistinctly zoned.

The largest population of zircons is iterpreted to represent the main crystallization stage of the host acidic magma at 300±4 Ma (latest Carboniferous – Stephanian). This may indicate that the climactic stage of volcanism in the Intra-Sudetic Basin occurred ca 10 My earlier than assumed to-date. The smaller, significantly older zircon population, 343±7 Ma in age, seems to reflect an Early Carboniferous magmatic event recorded in the rock sample. The few evidently older zircon crystals are inherited materials.

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Monazite as a tracer of magmatic and metamorphic events – examples from magmatic bodies in the Sudetes

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Monazites are important accessory phases in acidic metamorphic and igneous rocks. They retain information not only on the age of the main thermal events in the host rocks but point to the reactions and processes that release the components to build up/dissolve new fractions of monazites (Williams et al. 2007). Two examples of the use of monazite as an important petrological tool are presented. The first use is as a valuable source of age determination in thermally altered metamorphic rocks, the second as an indicator of hydrothermal alteration induced by the Strzegom granitic body.

The Kłodzko-Złoty Stok intrusion (KZI) thermally influenced the various types of rocks that it intruded (Bachliński, Bagiński 2007; Bagiński 2001), including pelitic rocks of the Bardo unit. Various types of hornfelses were developed. The most interesting, as a potential source of information on the pressure, temperature and timing of the processes, are sillimatite-corundum-hercynite hornfelses with garnet. Additionally they contain minute grains of accessory monazite. Chemical EPMA of fairly homogeneous monazites, growing as minute crystals (up to 30 micrometers) within different mineral phases, show the age of crystallization to be approx. 330±30 Ma (the age of thermal aureole formation). This age is very similar to ages from the Niemcza zone (Oliver et al. 1993).

Hydrothermally-altered granites in the Strzeblów quarry display an unusual concentration of monazite crystals at the contact between intermediate (small enclaves) and salic magmas. Careful study of monazite textures and compositions points to magma mixing as a main factor. Monazite alteration textures point to the considerable mobility of LREE caused by deformation and hydrothermal fluids. Additionally, the measured age of monazite formation is 301±10 Ma, consistent with previous results (Turniak et al. 2007).

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First occurrence of arsenian hydroxylellestadite in UHT-LP skarns of the Northern Caucasus, Russia

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Arsenian hydroxylellastadite has been discovered in high-temperature skarns in calcareous xenoliths in ignimbrites of the Upper-Chegem volcanic structure, Northern Caucasus, Kabardino-Balkaria Republic, Russia. This is the first worldwide discovery. This mineral belonging to the apatite supergroup is found in all skarn zones showing different degrees of hydrothermal alteration. It is associated with a variety of high-temperature minerals, namely, larnite, wollastonite, rondorfite, cuspidine, reinhardbraunsite, wadalite, lakargiite, magnesioferrite and bitikleite-(SnAl) corresponding to the sanidinite metamorphic facies. It also occurs among secondary low-temperature minerals such as calcium hydrosilicates (hillebrandite, awfillite, bultfonteinite), hydrogarnets, hydrocalumite and minerals of ettringite group. Arsenian hydroxylellestadite often forms elongated cracked hexagonal crystals (< 250 µm) as well as grain aggregates. The main type of isomorphic substitution is $(SO_4)^{2-} + (SiO_4)^{4} \rightarrow 2(AsO_4)^{3-}$. Based on microprobe analyses, the calculated empirical formula is $(Ca_{4.99}Fe_{0.01})_{\Sigma=5}[(SiO_4)_{1.31}(SO_4)_{1.04}(AsO_4)_{0.46}(PO_4)_{0.06}(CO_3)_{0.13}]_{\Sigma=3}[(OH)_{0.60}Cl_{0.15}\square_{0.14}F_{0.11}]_{\Sigma1}$

The Raman spectrum of arsenian hydroxylellestadite shows the following bands: 3602 cm^{-1}, 3570 cm^{-1}, 3510 cm^{-1}, 1134 cm^{-1}, 1100 cm^{-1}, 1003 cm^{-1}, 999 cm^{-1}, 958 cm^{-1}, 879 cm^{-1}, 853 cm^{-1}, 834 cm^{-1}, 644 cm^{-1}, 623.5 cm^{-1}, 568 cm^{-1}, 531 cm^{-1}, 469 cm^{-1}, 432 cm^{-1}, 385 cm^{-1}, 273 cm^{-1}, 135 cm^{-1}, 111 cm^{-1}. The content of arsenic in the hydroxylellastadite decreases inwards from the ignimbrite-skarn contact zone to the center skarn (from As = 1.20 *apfu* to As = 0.01 *apfu*).

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Characterization of historical plasters from the sgraffito in Bożnów (SW Poland) – preliminary results

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The purpose of our work is to fully characterize historic plasters used in the two-color sgraffito decoration in order to choose proper restoration techniques. The decoration is located on the northern wall of the western tower of the church in Bożnów, a small village situated in SW Poland. The decoration was completed by Christoph Rutsch and his two assistants in 1609. White plaster (primer plaster) was covered with a layer of a lime (sgraffito) plaster colored gray where the ornaments were scraped off.

In order to evaluate the deterioration of plasters and their composition, non-destructive methods (Infrared Thermography (IT) and ground penetrating radar (GPR)) carried "in-situ" were applied, followed by destructive techniques (optical microscopy (OM), sieve analysis, chemical analysis (Atomic Absorption Spectroscopy (AAS) and Atomic Emission Spectroscopy (AES), scanning electron microscopy (SEM), X-ray powder diffraction (XRD), Infrared spectroscopy (IR), and differential thermal analysis (DTA). The non-destructive methods were repeated after the completion of restoration works, which allowed the efficiency of the treatment performed to be evaluated.

Today, about 70% of the original sgraffito decoration is preserved. The non-destructive tests showed that before conservation treatment, a large proportion (ca 90%) of the decoration was exfoliated from the wall. Thermograms and GPR scans revealed the inner structure of the decoration, which allowed us to select the most appropriate sampling areas.

The mineralogical studies showed that the decoration comprises two separate coats of lime plasters, differing in the composition of their filler. The primer plaster and the sgraffito plaster are mixtures of lime binder (aerial lime) and fine- to medium-grained sand, showing related bimodal grain-size distributions and grain morphologies. The sand is dominated by quartz, feldspar and lithic grains (granitoids and ryolites) accompanied by less common biotite, amphibole and zircon. The difference is that the primer plaster contains a small amount of brick chunks and charcoal, while the sgraffito plaster is strongly enriched in the latter (occurring as chunks as well as superfine dust). Though the charcoal primarily served as a coloring agent, its porosity contributed to improved air permeability in the sgraffito plaster, accelerating the carbonation rate of the lime.

For elimination of the plaster exfoliation, a calcareous PLM-A product of C.T.S. Italy was applied by injection. The non-destructive studies performed after this conservation enabled the efficiency of plaster consolidation to be assessed, demonstrating that the rehabilitation work had reestablished the homogeneous structure of the plasters and proving the high efficiency of the consolidation treatment.

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Minerals formed by exhalation on the burning coal-waste dumps of the Upper Silesian Coal Basin, Poland

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Minerals formed due to exhalation on self-ignited coal dumps are widely described as, in this environment, a great variety of minerals of different chemical composition and habits can precipitate. As coal is the main source of elements for the newly-formed metastable minerals, they commonly contain ammonium, sulphur and chlorine.

Exhalation minerals were collected on (1) the eastern slope of the Katowice-Wełnowiec dump, (2) the southern slope of the Katowice-Wełnowiec dump, (3) the Chwałowice dump and (4) the Marcel dump. All of the collection sites differ in measured temperature, and time and volume of burning material.

In the Katowice-Wełnowiec dump, burned sites are local, located at shallow depths and rather short-term. In contrast, fires on the dumps in Chwałowice and Marcel were long-lasting, very intense and involved huge volumes of deposited material.

Mineral phases were determined by XRD and chemical compositions, mineral habits and associations by SEM-EDS. Exhalation minerals are translucent and typically white and yellow in colour. The presence of algae or bacteria can give them a green colour.

Only native sulphur was collected from the eastern slope of the Katowice-Welnowiec dump where the surface temperature has not exceeded $59^{o}C$ and the subsurface temperature at 30 cm was $85^{o}C$. Additional crystals observed under the scanning microscope appear to be orthorhombic though some have monoclinic habits.

On the southern slope of the Katowice-Wełnowiec dump, only salammoniac $(NH_4)Cl$ precipitated. In February 2010, measured temperatures reached $85^{o}C$ on the surface and $460^{o}C$ at a depth of 30 cm. It is a site of recent burning in the dump.

The coal dump in Chwałowice has been on fire for five years. The temperature on the surface is $60^{o}C$ and $370^{o}C$ at a depth of 1 m. Salammoniac $(NH_4)Cl$, orthorombic native sulfur S, pentahydrite $Mg(SO_4)\cdot 5H_2O$ and hexahydrite $Mg(SO_4)\cdot 6H_2O$, thenardite Na_2SO_4 and sylvite sodian $K_{0.6}Na_{0.4}Cl$ were collected there.

Extensive long-term burning in the Marcel dump resulted in the formation of millosevichite $(Al,Fe^{3})_2(SO_4)_3$, alunite $KAl_3[(SO_4)_2|(OH)_6]$, *steklite* $K,Al(SO_4)_2$, anhydrite $CaSO_4$, lesukite $Al_2(OH)_5Cl\cdot 2H_2O$, godovikovite (NH_4) $(Al,Fe)(SO_4)_2$, koktaite $(NH_4)Ca(SO_4)_2\cdot H_2O$, iowaite $Mg_4Fe(OH)_8OCl\cdot 4H_2O$, voltaite $K_2Fe_5^{3+}[SO_4]_4\cdot 18H_2O$ and hematite Fe_2O_3. The temperature measured 30 cm subsurface in place where samples were collected was $502^{o}C$. The presence of such unusual minerals in the coal dumps of the Rybnik coal area was described by Parafiniuk and Kruszewski (2009).

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Continental crust evolution: insight from Hf and O isotopes in zircons from Upper Carboniferous to Lower Permian volcanic rocks (drill cores from north-eastern Germany).

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A large volcanic province was formed during the initial stage of the Central European Basin System at the Carboniferous-Permian transition. Breitkreuz et al. (2007) dated zircons from 11 drill cores in the area to characterize the time span of the volcanic activity and the chronostratigraphic structure of the crustal basement which contributed material for the volcanism. SHRIMP zircon ages for the volcanic rocks range from 303 to 290 Ma with the major peak of the volcanic activity being at 299-295 Ma. The inherited ages from the drill cores range from 320 to 2614 Ma with two major peaks at ca 1.5 Ga and 1.0 Ga. Such age distribution indicates that the basement sampled by volcanism could be correlated with the Avalonia terrane (Breitkreuz et al. 2007).

In our study, we characterized the model ages and diversity of the East Avalonia basement by means of Hf and O isotopes measured in zircons from three drill cores which were previously dated by Breitkreuz et al. (2007). The drill cores are Penkun 1/71 – 15 zircons, Fehmarn Z1– 16 zircons and Salzwedel 2/64 – 18 zircons. Zircons that crystallized during the volcanic activity, ca 290-300 Ma, plot mostly on a trend of increasing εHf with decreasing δO^{18} consistent with mixing between mantle-derived magmas and an old crustal component. The range of εHf is from -7.3 to 1.0 with Penkun and Salzwedel zircons characterized by lower εHf than Fehmarn zircons. Hf model ages for zircons with the lowest εHf are ca 1.7-2.0 Ga, which indicate the presence of such an old crustal component within the East Avalonia terrane. However, the high δO^{18} of those zircons (ca 9.0 ‰) shows that the model ages are probably hybrid and represent reworking of an even older crust and the mixing of crust and mantle components before the Carboniferous/Permian volcanic activity.

A better understanding of the crustal basement comes from analyses of inherited zircons. Consistent data were obtained for ca 1.5 Ga old zircons. Five out of the six analyzed zircons show similar primitive δO^{18} (5.9-6.2 ‰) and similar εHf (-1.7 - + 3.6). Such zircons occur in all three of the studied drill cores suggesting that a large portion of the East Avalonia terrane could have been formed at that time. That crust was later reworked at ca 1.0 Ga consistent with the presence of inherited zircons of that age with higher δO^{18} but similar εHf compared to the 1.5 Ga old zircons.

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New data on uranium minerals from Wołowa Góra (Karkonosze Mts, Lower Silesia, Poland)

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Brannerite is a mineral that can be regarded as one of the uranium ores. In Poland, its occurrence is confirmed only among the quartzose veins located on the slopes of Wołowa Góra, 3 km to the SW of Kowary, in the Karkonosze range. During the years from 1954 to 1957, a mine was worked here from which about 2.5 tons of uranium ore was extracted. To-date, the brannerite-bearing quartzose vein has been shown to also contain gersdorffite, pyrite, tourmaline (dravite), biotite, zircon, apatite and pharmacosiderite.

Brannerite occurs as prismatic crystals, reaching up to 3 cm in length. The mineral is black or brown and possesses a conchoidal fracture and glassy lustre. The researched brannerite is of highly metamict character. On BSE images, its crystals reveal nonuniform structure. The outer zones of the crystals bear the marks of the weathering-related alteration. The alterations can also be observed along cracks in the crystals. The chemical composition of the Wołowa Góra brannerite was dertermined using the EMPA technique. The empirical formula of non-altered brannerite is $(U_{0.64}Ca_{0.15}Y_{0.10}Th_{0.07}Pb_{0.02})_{\Sigma 2.00}(Ti_{1.65}Fe_{0.08}Nb_{0.07}Mn_{0.03})_{\Sigma 1.83}O_6$ and that of the altered brannerite is $(U_{0.56}Y_{0.15}Ca_{0.12}Th_{0.09}Pb_{0.02}Ce_{0.02}Nd_{0.02})_{\Sigma 2.00}(Ti_{2.03}Nb_{0.11}Fe_{0.09}Mn_{0.03})_{\Sigma 2.26}O_6$.

Numerous inclusions of thorite, up to 50 μm in size, occur within the brannerite crystals. These inclusions are always rimmed by altered brannerite. The thorite from Wołowa Góra belongs to the thorite-coffinite solid solution and has the following empirical formula: $(Th_{0.63}U_{0.20}Ti_{0.07}Ca_{0.07}Y_{0.06})_{1.03}SiO_4$. In some instances, the thorite is associated with tiny aggregates of uraninite.

Within the outer parts of the brannerite crystals, segregations of titanium oxides are evident. These oxides are represented by a phase containing from 74.01-86.05 wt% TiO_2 that is also distinctly enriched in Nb (3.15-5.58 wt% Nb_2O_5) and uranium (3.05-4.36 wt% UO_2). In the altered brannerite, segregations of some unidentified, secondary phases rich in uranium (41.72-57.91 wt% UO_2), titanium (15.94-21.70 wt% TiO_2), thorium (3.81-10.65 wt% ThO_2) and phosphorus (5.56-6.15 wt% P_2O_5) also occur.

In the vicinity of the brannerite crystals that have undergone weathering, decomposition products of supergene character occur. Among these, the prevalent one is a mineral belonging to the metaautunite-chernikovite solid solution that forms pale-yellow, thin, tabular crystals. This mineral is also accompanied by sabugalite.

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New data on secondary uranium minerals from the Western Sudetes (Poland) – preliminary report

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Secondary uranium minerals are known from the W Sudetes since the end of the XIXth century. The identification of these phases was usually based on the macroscopic observations, insufficient for correct recognition. The purpose of the research to provide a reconnaissance overview of the occurrence of supergene U minerals at different sites, namely, at the inactive uranium mines in Wojcieszyce, Radoniów and Kopaniec (the Izera Foothills), Kowary and Wołowa Góra (the Karkonosze Mts) and the traces of U mineralization in the granitoid pegmatites of Skalna Brama (the Karkonosze Mts).

The presence of sabugalite was confirmed in Wołowa Góra. This mineral forms thin, pale-yellow, finely-crystalline coatings on the surface of brannerite-mineralized quartz. The crystals of sabugalite can reach 75 μm in size. In some samples, replacement of crystals of the metatorbernite-chernikovite solid solution phase by sabugalite is observed. The empirical formula of the sabugalite from Wołowa Góra is:
$H(Al_{1.21}Ca_{0.18}Ba_{0.18})_{\Sigma 1.57}(UO_2)_4[(PO_4)_{3.34}(AsO_4)_{0.17})]_{\Sigma 3.51}\cdot 10.57H_2O$.

Saléeit is a relatively common mineral occurring on the dumps in Wojcieszyce. It forms thin, tabular crystals reaching 1.5 mm in size. These are usually aggregated into radiating or fan-like forms of white-yellow colour. Microprobe analysis has shown that the mineral represents the magnesium member of the saléeite-autunite solid solution with the following formula: $(Mg_{0.73}Ca_{0.03}Fe_{0.03}K_{0.03})_{\Sigma 0.82}(UO_2)_2(PO_4)_{1.85}\cdot 3.35H_2O$. That the water content in the saléeite from Wojcieszyce is lower than the theoretical value probably reflects crystallization water loss during the EMPA analyses.

Meta-autunite, one of the most common weathering U minerals in Radoniów and Wołowa Góra, forms yellow, tabular crystals up to 0.5 cm in size. Their chemical compositions correspond, at Radoniów, to the intermediate members of the meta-autunite–chernikovite–meta-ankoleite solid solution with the mean formula: $[(H_3O)_{0.28}Ca_{0.77}K_{0,06}]_{\Sigma 1.01}(UO_2)_2(PO_4)_{1.96}\cdot 6.27H_2O$ or, at Wołowa Góra, to meta-autunite–chernikovite: $[Ca_{0.50}(H_3O)_{0.39}Ba_{0.02}Cu_{0.01}]_{0.92}(UO_2)_2[(PO_4)_{1.80}(AsO_4)_{0.02}]_{\Sigma 1.82}\cdot 3.82H_2O$. In Radoniów, this mineral is commonly associated with an unspecified phase chemically close to becquerelite. In the area of the Kopaniec mine, tabular, pale-green crystals of an intermediate member of the chernikovite-torbernite solid solution were also identified.

Uranophane is also one of the most common secondary U minerals in the W Sudetes. For example, in samples from Kowary-Podgórze, the mineral forms aggregates reaching 0.4 cm in diameter. Uranophane occurs also within the Skalna Brama pegmatites. There, the mineral forms coarsely-crystalline, yellow crusts covering crystals of feldspar that contain the aggregates of efflorescent gadolinite.

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Atoll-like andradite garnet from the hydrothermally altered quartz-diorites from Starorobociański Peak (Western Tatra Mts., S Poland)

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Hydrothermal alterations of hybrid quartz-diorites from the Western Tatra Mts are rarely observed and usually restricted to chloritization of mafic minerals in the fractured and sheared rock-portions. In Starorobociański Wierch, at the contact of mafic diorite with felsic tonalite, a zone about 0.5-0.7 mm thick, rich in chlorite in which local concentrations of ellipsoidal atoll-like garnets were found.

The parental rocks are: * quartz diorite, composed of Mg-hornblende (***fm*** = 0.263-0.342), plagioclase (An_{30-40}), green biotite (***fm*** = 0.360-0.371), quartz, zoned allanite-epidote, and accessory apatite, magnetite, zircon and sporadic partial pseudomorphs after pyroxene; ** granodiorite-tonalite composed of plagioclase (An_{20-29}), K-feldspar, biotite (***fm*** = 0.59-0.619), quartz and accessory apatite, ilmenite and zircon.

The atoll-like andradite-grossularite garnets are composed of skeletal grains and show variations in composition from $And_{48}Gr_{48}Alm_3Py_4$ – $And_{59}Gr_{38}Alm_2$ in cores to predominantly andradite near rims ($And_{69}Gr_{35}Alm_2$ – $And_{82}Gr_{15}Sp_1Alm_1$). Locally K-feldspar forms the core of the atoll-like structure. More commonly, K-feldspar is intergrown with garnet in the external parts of the structure. In the outer part of the atoll-like structures as well as in the chlorite matrix, numerous skeletal Al-rich and F-rich titanite crystals are present. The matrix chlorite surrounding the atoll-like structures is magnesium-rich (***fm*** = 0.301-0.326), similar to the chemistry of primary mafic minerals. In the absence of garnets, epidote is present. Mg-hornblende at the contact with the reaction zone is transformed to actinolite – Fe-actinolite characterised by inherited ***fm*** in the range of 0.219-0.399. Magmatic feldspars are replaced by the assemblage Ab + Kfs + Ep.

The mechanism proposed for the formation of the atoll-like garnets can be linked to metasomatic alterations at the junction between mafic and felsic magmas. The strong oxidation conditions in the hydrothermal fluid forced the formation of zoned, Fe^{+3}-rich (grossularite-andradite) garnets. Possible reactions leading to the presently observed mineral assemblages could be: Ti-Bt + An = Grt/Ep + Ttn + Chl + Kfs (mean volume proportions of the products: 40% Grt + 42% Chl + 9% Ttn +9% Kfs), and Ttn + An + Bt + V = Ilm + Czo + Kfs + Qtz. As no rutile was found, it is possible that the a_{SiO2} was kept high enough and the reactions Px + An + H_2O = Ttn + Fe-Act + Qtz could also occur. As the secondary epidote usually coexists with Kfs and Ab, possible reactions are as follows: Olig + Hbl + V = Czo + Chl + Ab + Qtz.

The formation of the garnets could be linked to the metasomatic alterations at the contact of two chemically-different magmatic rocks, also creating the oxidation gradient. Introduction of external Ca-rich and F-rich fluid cannot be excluded.

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Magma mixing in the common Tatra-type granite in the light of textural and cathodoluminescence features – a comparison with the High Tatra-type

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The division of the Tatra granite body into High Tatra and common Tatra types was made by Kohut and Janak (1994). Their division does not follow the classical division of Morozowicz (1914) into the Koszysta and Goryczkowa types, and they do not discuss the idea of Tokarski (1925) concerning the unity of the Tatra granitoid magmatism. The High Tatra granite has been documented to be characterized by mixing-mingling phenomena and, consequently, by textures typical of such.

In the common Tatra granite, textures characteristic of mixing/mingling of felsic and mafic magmas also occur (textural assemblage - according to Hibbard, 1991) and are as follows: presence of mafic magmatic precursors (quartz-diorites), titanite-feldspar, titanite-quartz and hornblende-quartz ocelli, mixed apatite morphologies and local concentrations of apatite-rich cumulates, mafic cloths (Bt + Mg-Hbl + Mt/Ilm), K-feldspar and plagioclase porphyrocrysts with internal chemical zonation underlined by rows of mineral inclusions, calcic spikes in plagioclases, reversed zoning in matrix K-feldspars.

Zoned Afs and plagioclase phenocrysts (0.5-2 cm in size) from different localities were studied by means of EMPA and CL as they are indicators of magmatic processes. Two types of alkali feldspars were distinguished: 1st type – Afs forming cumulative structures, both with and without apatite concentrations. 2nd type – Afs dispersed in homogeneous grey granite. Alkali feldspars of the 1st type show inverted chemical zonation and relatively low Ba contents (< 3 at% Cn). Locally, weak oscillations can be traced in CL as shades of blue colour caused by Al-O-Al defects. The zonation is underlined by inclusions of yellow luminescing apatite. Coexisting plagioclase crystals in cumulates show a greenish luminescence. Alkali feldspars of the 2nd type show normal chemical zonation (in general) with oscillations (0.4-3.5 at% Cn) traced both by rows of plagioclase inclusions (synneusis), CL and EMPA. Both the included- and overgrowing plagioclases nucleated on the Afs growth surfaces. Locally, magmatic albite-oligoclase overgrowths form rapakivi structure.

Temperature calculations indicate the predominance of post-magmatic conditions (524-550^{o}C) and most probably a late thermal episode related to shearing and alkali-element migration. Equilibrium magmatic temperatures (T = 770-776^{o}C) and close to equilibrium magmatic temperatures (810-820^{o}C) are also preserved.

Textural comparison and the alkali feldspar features lead to the conclusion that both the High Tatra and common Tatra granites types probably represent the same magma intrusion, differing in the degree of mafic magma contamination.

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Eclogites from the Piława Górna quarry (Dolnośląskie Surowce Skalne S.A.), Góry Sowie Block, SW Poland: a preliminary report

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Heterogeneously retrogressed eclogites composed of garnet, clinopyroxene, spinel, plagioclase, amphibole, quartz, biotite, rutile, ilmenite,and clinozoisite were discovered in the Piława Górna Quarry. They form a body several meters thick enveloped by migmatic gneisses, and display very weak foliation. On the basis of microscopic and microprobe studies, the first assemblage was garnet, omphacite, kyanite, quartz, clinozoisite, and rutile, now mostly preserved as inclusions in garnets porphyroblasts. The second assemblage comprised garnet (rims), hornblende, sodic diopside, plagioclase, spinel, biotite and ilmenite. The growth of this assemblage was marked by the development of plagioclase–amphibole coronas around garnet porphyroblasts, sodic diopside–plagioclase and spinel–plagioclase symplectites pseudomorphing omphacite and kyanite crystals, respectively. Preliminary thermobarometric calculations derived from the composition of pyroxene, garnet and amphibole have indicated that the first metamorphic episode took place at high pressures, reaching 16.5-17.1 kbar at temperatures of 720-760°C. The HP event was followed by a second metamorphic episode under amphibolite facies conditions: 8.3-6.7 kbar at 690-640°C. Retrogressive growth of amphibole rarely failed to eradicate the phases from the HP event, and consequently amphibolites are widespread in the quarry. The results indicate a nearly isothermal, probably rapid, decompression of ca 9-10 kbar, corresponding to an uplift of ca. 30-35 km. These results are consistent with data reported for the HP rocks (granulites) from the Góry Sowie block (e.g. Kryza and Manning 2007); the lower P and T values obtained in this study may indicate either post-peak re-equilibration of the HP assemblage or the studied rocks reaching a shallower crustal level on their prograde path than the other HP rocks in the block.

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Olivine phenocrysts: a tool to reconstruct the crystallization history of basaltoids from the Niemodlin area (SW Poland)

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The Tertiary volcanic rocks of the Niemodlin area (SW Poland) belong to the easternmost part of the Central European Volcanic Province (CEVP). Here, we will present new data from two active quarries "Gracze" and "Rutki-Ligota".

According to the TAS diagram, the rocks from Gracze are nephelinites and basanites and those from Rutki-Ligota are basanites. Trace elements characteristic of the rocks are typical of OIB. However, the rocks from Gracze have higher contents of incompatible elements (Th, U, La, Ce) than do those from Rutki-Ligota, which may indicate that the latter represent a more extensively melted mantle source.

Mineral compositions are very similar in both groups of rocks. The basanite consists of olivine, clinopyroxene, nepheline, plagioclase, Ti-Fe oxide and apatite. The nephelinite consists of olivine, clinopyroxene, nepheline, Ti-Fe oxide and apatite. Phenocrysts in both groups are olivine and clinopyroxene.

The rocks from Gracze quarry contain more MgO (ca 13 wt%) than the basanites from Rutki-Ligota (ca 11 wt%). However, the chemical composition of olivine from these rocks is similar. Changes in the Fo (forsterite), Ca and Ni in olivine are best visualized in a plot of distance from the olivine rim [μm] against Fo, Ca and Ni contents. Higher values of Fo and Ni are consistently observed in the cores of phenocrysts, whereas Ca contents in the cores are the lowest. Cores are characterized by Fo_{85-89}, which rapidly decreases to Fo_{73} ca 100-150 μm from the rim. On the other hand, Ni decreases steadily from core to rim, which is consistent with crystallization of mostly olivine from the magma. The only differences between the olivine compositions from the two localities are the Ca contents. In the Gracze quarry, two types of olivine phenocrysts occur, with high (>1000 ppm) and low Ca (<1000 ppm) contents in the cores. Olivine phenocrysts in basanites from Rutki-Ligota have compositions similar to the high-Ca phenocrysts. On the diagrams depicting Fo in olivine vs Mg/(Mg+Fe) (Mg#) in whole rocks and CaO in olivine vs CaO in whole rocks, we observe that the cores of the olivine phenocrysts from Rutki are in equilibrium with both Mg# and CaO wt% content in the whole rock and can therefore be interpreted as a simple crystallization from a melt of the whole-rock composition. On the other hand, only low Ca olivines from Gracze are in equilibrium with the whole rock Mg#, but they are clearly not in equilibrium with whole-rock CaO wt% content. This discrepancy can be explained by crystallization of olivine phenocrysts in two different magmas followed by mixing. The general similarity between the high Ca olivine from Gracze and the olivine from Rutki suggests that one of the magmas was similar in composition to that from Rutki. The second magma was in equilibrium with low-Ca and higher MgO contents and lower alkali (Libourel 1999). Such magma would be close to a MORB-like composition in contrast to the generally alkaline magmas occurring in the CEVP.

The other possibility is that the second magma started crystallizing at lower depths at which Ca partitioning between olivine and melt was low.

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P-T-d paths of metasedimentary rocks in the Staré Město Belt, NE Bohemian Massif

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The Staré Město Belt (SMB) is the narrow, 55 km long, NNE-SSW trending, WNW dipping tectonic zone that separates the Orlica-Śnieżnik Dome (OSD) in the west from the Moravosilesian domain (MD) in the east. The SMB consists of three lithotectonic segments. The Hranična, belt mainly composed of mica schists and felsic metavolcanites, is the westernmost 1-3 km wide segment of the SMB; it was underthrust to the west beneath gneisses of the OSD. The axial part of the SMB is occupied by Cambro-Ordovician leptyno-amphibolitic complex in the middle of which a ca 340 Ma old tonalite body occurs, accompanied by mica schists and paragneisses. The West Nýznerov Thrust separates the leptyno-amphibolitic complex from the Skorošice mica schists and amphibolites.

Based on overprinting and structural-metamorphic relationships, four generations of deformation structures were recognized in the metasediments of the SMB. The earliest recognizable structure, a foliation S1, is defined by compositional banding of quartzo-feldspathic and mica-rich domains folded by F2 folds. On a microscale, the S1 is defined by Otz-Rt-Ms±Chl±St±Ma inclusion trails preserved in garnet cores. The dominant penetrative foliation, S2, is axial planar to tight-to-isoclinal, E-verging, mesoscopic F2 folds. S2 generally parallels the SMB tectonic boundaries and dips moderately or steeply to the WNW. F2 and S2 presumably developed as a result of the Variscan underthrusting of the MD domain beneath the OSD. The NCKFMASH pseudosection and St, Chl and Grt compositional isopleths calculated for Grt-Chl-St-Ma(±Pl) parageneses in mica schists of the Hranična belt reveal that this event was associated with a temperature increase followed by pressure drop from 9 kbar at 530°C to 7 kbar at 580°C. The increasing-temperature path during initial decompression indicates that the rocks of the Hranična belt were quickly exhumed, possibly due to their emplacement along a thrust fault which developed during the progressive eastward thrusting. This thrust fault, locally defined by a mylonite zone a few meters thick, separates mica schists of the Hranična belt from the leptyno-amphibolitic complex.

The S2 planes were zonally reactivated as the S3 foliation during subsequent ductile shearing. Shear sense indicators including σ-clasts, C'-planes and asymmetrical folds indicate top-to-the-NW(N) (dextral) movement along the S3||S2 foliation. During this stage, the emplacement of the tonalite sill in the axial part of the SMB took place. Within the contact aureole of the sill, evidence of in-situ partial melting of metapelites, and associated granitic segregations ranging from small ovoid patches to distinct subparallel-to-foliation veins < 20 cm thick, are observed. Isopleth thermobarometry in NCKFMASH applied to Grt-Bt-Ms-Pl paragenesis in the Hranična schists indicates that this stage was locally associated with nearly isobaric heating from 550 to 650°C at ca 7.0 kbar.

Metapelitic inserts in the leptyno-amphibolitic complex experienced slightly higher temperatures compared to those calculated for the Hranična belt. Both conventional- and isopleth thermobarometry in the KFMASH system for Grt(rim)-Bt-Ms-Sill reveal that these rocks reached ca 680°C at 7 kbar. In this case, however, it is possible that the calculated values correspond, not to the Variscan, but to the Ordovician HT thermal event. The last generation of structures, the F4 folds, are open, doubly vergent both E- and W-ward and lacking an axial foliation.

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Crystallization and cooling history of Męcinka and Winna Góra basaltoids

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The basaltic rocks occurring in the vicinity of Jawor (SW Poland) belong to the Cenozoic Central European Volcanic Province. The basalt occurrences comprise a volcanic plug, lava flows and dikes. The lava flow is exposed in the Męcinka quarry and the volcanic plug in Winna Góra. These occurrences are 3 kilometers away from each other. According to TAS, two types of basaltoids occur in Męcinka, i.e., basalt and basanite and, in Winna Góra, basanite and trachybasalt. The matrix in each of these groups consists of plagioclase, diopside, Ti magnetite/ilmenite, nepheline and glass. Olivine and, rarely, clinopyroxene occur as phenocrysts.

The major differences between the basalt and basanite at Męcinka are observed in the compositions of olivine phenocrysts. Two types of basalt occur, the first with Fo content from 74-68%, the second from 80-76% (core-rim respectively). Olivine porphyrocrysts from the basanite rocks typically contain 85% Fo in cores and 80% in margins.

CSD results reveal different crystallization regimes in the basaltic and basanitic rocks at Męcinka. The early stage of crystallization was longer for the basalt than for basanite. Basalt and basanite probably come from two different injections. Late stage (after eruption) crystallization was also longer for basalt. Both groups (basalt and basanite) could represent different stages of eruption or different lava flows. Shorter crystallization times in basanite than in basalt, and thus probably higher undercoooling, could be responsible for higher % Fo in basanitic olivines compared to those in the basalt. Interestingly, a diagram of Fo content in olivine vs. #Mg number in whole rock shows that only the cores of the olivine in the basanite crystallized in equilibrium with melt. This may suggest that the composition of the olivine in the basaltic rocks was strongly modified by diffusion.

Basanite and trachybasalt from Winna Góra also differ in the compositions of their olivine phenocrysts. Olivine porphyrocrysts in the basanite typically contain 90% Fo in cores falling to 65% in margins, and those in trachybasalt from 85% Fo in cores to 72% in margins. A diagram of Fo content in olivine vs. #Mg number in whole rock shows that the cores of the basanite olivine crystallized in equilibrium with melt, whereas not all trachybasalt olivine cores did so.

There are significant differences in olivine composition between Męcinka and Winna Góra and between different rock types in these occurrences. The diffrences can be related to lack of equilibrium with melt during crystallization, diffusion processes or involvement of more primitive magma.

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Mineralogy and geochemistry of historical slags from the Rudawy Janowickie Mountains: reconstruction of smelting conditions

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Metallurgy is one of the oldest domains of applied sciences. Its history can be traced back through multidisciplinary studies of old slags. Modern mineralogical and geochemical studies of historical slags enable the reconstruction of former smelting techniques and show how metallurgy evolved through human history.

The polymetallic (Cu, As and Ag) mineralization in the Rudawy Janowickie area originated from hydrothermal solutions related to the Variscan intrusion of the Karkonosze Granite. The ore forms veinlets inserted in fracture planes within metamorphic rocks such as amphibolites, chlorite and mica schists. The ore consists of chalcopyrite with minor bornite and pyrite.

Mining and smelting of Cu ores in the Rudawy Janowickie area (Lower Silesia) started in the XIV century. Since then, exploitation re-commenced several times before it finally ceased entirely in 1925, leaving unattended mining pits and dumps.

The studied slags are isometric with sizes ranging from a few to dozens of centimeters. On the basis of textural characteristics as well as bulk chemical composition, I distinguished two types of slags. The dominant type is black, has aphanitic, massive texture and commonly displays flow textures. Its chemical composition is dominated by FeO (up to 51 wt%), SiO_2 (up to 43 wt%) and Al_2O_3 (up to 12 wt%). It consists of silicate glass, fayalite and hercynite with minor amounts of sulfides. The second slag type is highly porous and contains pieces of unmelted quartz gangue. It is poorer in FeO (up to 28 wt%) and richer in SiO_2 (up to 70 wt%) than the dominant type of slag. It consists of silicate glass, ferrosilite, cristobalite and quartz.

Low contents of CaO (up to 1.7 wt%) shows that lime as a melting agent, which is frequently used in modern metallurgy, was not added to the furnace during the smelting of Cu ores in the Rudawy Janowickie. Partially melted quartz grains observed in porous slag originate either from unmelted gangue or from addition of quartz as a flux. Sulfur contents in both types of slag never exceed 1 wt% (average 0.6 wt%) which indicates rather efficient roasting of the furnace charge. Although upper temperature levels in historical smelting furnaces is estimated to be lower than 1300°C, the presence of cristobalite in the porous slags studied indicates that they formed at the temperature of at least 1470°C.

The results of my study show that a range of mineralogical and geochemical methods can be applied to the study of historical slags and can be successfully used to reconstruct smelting conditions.

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Mineralogy of baroque mortars from tenements in Lądek-Zdrój (SW-Poland)

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Baroque tenements in Lądek Zdrój, situated in Marketsquare 1, 6 and 7, date from the 17th and 18th centuries. They were partially rebuilt after fire in the 2nd half of the 18th century. These tenements, decorated with sculptural elements by Michał Klahr, a prominent sculptor of the Baroque era, are considered the characteristic baroque works of the Kłodzko region.

In 2007, façade renovations to tenements in Market 1 and Market 6 enabled sampling of the original mortars for detailed mineralogical studies. Their composition and condition, as determined by our studies, provided a basis for planning and for subsequent preservation works.

Various technological layers of mortar were indentified during our field-work. These are 1) primer mortar, 2) finishing mortar, 3) join mortar, 4) rendering mortar used for stuccowork and 5) secondary mortar (presumably applied at some time after the fire). All of the layers were carefully sampled. The samples were analyzed using polarizing microscopy, X-ray diffraction and differential thermal analysis.

All of the mortars display the same micritic binder mass (matrix) with common microcracks that reflect the shrinkage of applied lime. Locally, the micrite is weathered and replaced by secondary gypsum. The baroque mortars are characterized by distinct, rounded lime lumps in the micritic matrix. In most cases, these lumps are porous and composed exclusively of micrite, though a few contain relics of underburnt limestone fragments. The binder of the secondary mortars is relatively homogenous and free from lime lumps and other binder-related particles.

The main difference between mortars lies in their diverse fillers. Typically, the original baroque mortars (plasters and joint mortars) have medium- to coarse-grained fillers dominated by angular rock-fragment grains (gneiss, mica schist, marble), quartz and less common feldspars with accessory micas, staurolite and garnet. The filler of the finishing mortar is finer-grained in comparison to the filler of the primer mortar. The rendering mortars have fillers composed of angular basalts and less common rounded to subrounded quartz. The filler of the secondary mortar is fine to medium-grained and composed of rounded to subrounded quartz and less common feldspars and rock-grains (granitoids).

Petrographic studies show that aggregate from various, possibly local, deposits was used as filler in the manufacture of the mortars. Part of this aggregate is a rubble stone, mined from near a basalt quarry in Lutynia. Other parts comprise eluvium of metamorphic rocks present on the ground surface and, others, mature fluvioglacial sediment or river sand. Differences in the compositions of mortars depending on the site of application and their role in the buildings, show that the builders were aware of the use of natural ingredients in architecture and skilled in selecting appropriate mixtures of ingredients which determine both the durability of monumental objects and their decorative aspects.

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The Central-Sudetic ophiolites: SHRIMP zircon geochronology (preliminary results)

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The Central-Sudetic ophiolites (CSO) are relatively well-preserved and broadly complete Palaeozoic ophiolitic sequences at the NE margin of the Bohemian Massif, near the eastern edge of the Variscan Belt of Central Europe. They comprise the largest and best-studied Ślęża ophiolite, the smaller Nowa Ruda and Braszowice massifs, and a few small exposures of ultramafic rocks along the eastern edge of the Góry Sowie Massif (Majerowicz 1979, 1994, Pin et al. 1988, Dubińska, Gunia 1997, and refs therein).

Pin et al. (1988) demonstrated the N-MORB-type geochemical and Nd–Sr isotopic signature of the Ślęża and Nowa Ruda ophiolites. The Ślęża ophiolite and other parts of the CSO were likely emplaced in a mid-oceanic ridge setting (Pin et al. 1988, Majerowicz 1994, Dubińska, Gunia 1997, Floyd et al. 2002).

The Sm–Nd whole-rock isochrons of Pin et al. (1988) were previously interpreted to record magmatic ages of 353±21 Ma and 351±16 Ma for the Ślęża and Nowa Ruda mafic rocks, respectively. Afterwards, Oliver et al. (1993) used the U–Pb conventional method on abraded zircons to analyse a few grains of that mineral recovered from a sample of the Ślęża gabbro. In spite of analytical problems, the calculated age of 420 +20/−2 Ma was interpreted to date the magmatic crystallization event in the gabbro.

Indirect geochronological constraints on the age of the Ślęża ophiolite were provided by Dubińska et al. (2004) based on the U–Pb abraded single-grain zircon method applied to a zircon separate obtained from a "metasomatic shell" of rodingite. Their age of 400 +4/−3 Ma was interpreted to date a zircon crystallization event during metasomatic processes connected with the serpentinization.

Kryza & Pin (2010) reported preliminary results on two samples of the Ślęża gabbros. One sample, representing felsic segregations in medium-grained gabbros, yielded $^{206}Pb/^{238}U$ ages scattered between c. 360 and c. 410 Ma, strongly suggesting that the zircons had suffered radiogenic lead loss. Based on the four oldest analyses, a weighted average age of 400±10 Ma was calculated. The other sample, representing light-coloured veins and segregations in fine-grained metabasalts of the subvolcanic member, provided a weighted average $^{206}Pb/^{238}U$ age of 403±6 Ma.

Further zircon "hunting" in gabbros of the CSO and new SHRIMP zircon investigations (Kryza 2009, unpublished data) provided $^{206}Pb/^{238}U$ ages as follows:

- Ślęża Massif, sample from felsic segregations in gabbro: ~ 395 Ma,
- Nowa Ruda Massif, medium-grained gabbro: ~ 404 Ma,
- Nowa Ruda Massif, diabase: ~ 395 Ma,
- Braszowice Massif, deformed coarse-grained gabbro: ~ 405 Ma.

The samples from the metagabbroic- and metavolcanic members of the Ślęża, Nowa Ruda and Braszowice ophiolites yielded similar SHRIMP results, as shown by examination of $^{206}Pb/^{238}U$ data which provide the most useful information as, in U-poor zircons, the determination of ^{207}Pb during in-situ measurement is plagued by gross analytical uncertainties (Kryza, Pin 2010). In all of the new samples, however, the $^{206}Pb/^{238}U$ dates are apparent ages that should be, strictly speaking, considered minimum estimates of the true igneous crystallization age. But, given that these ages were measured on zircons with extremely low concentrations of U (except for sample BR1), and that the metamorphic overprint throughout the ophiolitic body is moderate, it is reasonable to conclude that the zircons were resistant to lead loss and not strongly modified by late-stage disturbances and, therefore, broadly reflect the igneous crystallization stage of the Central-Sudetic ophiolites.

The preliminary new SHRIMP ages are in good agreement with the age obtained by Dubińska et al. (2004), implying that either serpentinization occurred very soon after igneous crystallization (if their interpretation of the metasomatic growth of zircon is correct), or that their zircons formed during the igneous crystallization of the gabbroic veins from which the rodingites were later formed, during an undated serpentinization event. The ages are also consistent with that of Oliver et al. (1993), albeit one obtained on a very small number of zircon grains from one gabbroic sample.

The new SHRIMP zircon ages are evidence for the magmatic emplacement of the CSO at c. 400 Ma. The ophiolites, interpreted as traces of the Rheic Ocean, are key arguments for reconstructing the early- to mid-Palaeozoic rifting processes. The CSO represent ca. 400 Ma oceanic-crust fragments, and their structural position delineates likely major Variscan tectonic sutures and tectonic-mosaic domains within the Variscan accretionary prism (Kryza, Pin 2010).

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Beryllium minerals (beryl, phenakite and bavenite) in pegmatites of the DSS mine at Piława Górna, Góry Sowie Block, SW Poland

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Occurrences of beryllium minerals are generally assigned to granitic pegmatites (Černy 2002). To-date, Be minerals have been found in Poland mostly in the Strzegom, Strzelin and Karkonosze granitic massives and in the Góry Sowie metamorphic block (Lis, Sylwestrzak 1986). Bavenite, phenakite, helvite, euclase are evident only in granitic pegmatite of the Strzegom massif.

The most common Be mineral in the Góry Sowie Mts is beryl, described in papers from many localities (Sachanbiński 1973, Łodziński 2007). Between 2008 and 2010, beryl was found widely in pegmatite veins in amphibolites and gneisses in the DSS mine at Piława Górna. It ocurs in various internal pegmatite zones, e.g. in feldspar-muscovite-tourmaline zones, 'sacharoidal' albite zones and quartz core zones. It forms macroscopically idiomorphic, prismatic crystals < 15 cm long and < 8 cm in diameter. Its colour is greenish, yellow, sometimes white and bluish. The Piława beryls are normal beryls (with limited substitutions in octahedral and tetrahedral sites) with < 1.85 wt% FeO, in accordance with previously published data on beryls from the Sowie Góry Mts (Łodziński 2007). They classify as sodic beryls, poor in alkalis or as sodic-caesium beryls, rich in alkalis < 0.66 wt% Na_2O and < 0.14 wt% Cs_2O.

Bavenite is found together with beryl in the paragenesis. It forms crystalline aggregates, platy in habit, with growth zones indicated by changing contents of Al_2O_3 (from 10.51 wt% in cores to 5.97 wt% in rims) and SiO_2 (from 58.43 wt% in cores to 61.52 wt% in rims). Bavenite, together with phenakite, also appears as aggregates inside beryl crystals. The paragenesis beryl-bavenite-phenakite in the Piława pegmatites can reveal the physico-chemical environment of pegmatite crystallization. Such minerals are sensitive indicators of alkalinity and suggest that increasing pH to 7-9 (bavenite → beryl) marked the end of the pegmatitic stage.

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Fe-rich tourmaline from the Orlica-Bystrzyca Metamorphic Unit, Sudetes, SW Poland

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Fe-rich tourmalines belonging to the schorl group occur in a recently opened quarry in metamorphic schists in Jawornica near Kudowa-Zdrój in the Orlica-Bystrzyca Metamorphic Unit. Typically, they occur within pegmatite veins cross-cutting sericite- and chlorite-sericite schists. They also occur in the crystalline schists themselves.

The pegmatite veins are light pink in colour. Quartz is a main constituent of the veins; it locally forms monomineral zones. It appears together with pink K-feldspar, fine platy muscovite, biotite, hematite and ore minerals. Accessory minerals include monazite-(Ce), zircon, xenotime, rutile and ilmenite. These commonly occur as solid inclusions in tourmaline crystals.

Distinct growth zones indicated by pleochroic colours are a particular feature of the tourmalines. Tourmaline cores are characterized by blue pleochroic colours and rims by brownish- and, rarely, greenish colours. The optical changes correspond to variations in chemical composition revealed by electron-microprobe analyses (SEM-WDS).

Tourmaline cores contain 35.28-36.00 wt% SiO_2, 31.05-33.07 wt% Al_2O_3 and 0.14-0.32 wt% TiO_2. Rims contain 34.65-35.51 wt% SiO_2, 26.85-30.29 wt% Al_2O_3 and 0.72-1.48 wt% TiO_2. Cores, compared to rims, are characterized by much less TiO_2 and increased Al_2O_3. The crystallization of tourmaline, and the origin of the pegmatite veins in the crystalline schists, is certainly related to the metamorphism of the Orlica-Bystrzyca Metamorphic Unit.

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Accessory minerals from mantle xenoliths from Wołek Hill and Wilcza Góra

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Secondary accessory minerals such as phosphates (ap and wh), sulfides (ccp, pn, mss, po), amphiboles and compositionally variable micas (Ti-Ba-rich) from mantle peridotites are broadly considered to be mantle metasomatism indicators (O'Reilly, Griffin 2000).

In this preliminary study, we present mineral chemistry and textural data for selected secondary metasomatic minerals from spinel peridotites of mantle xenoliths from Wołek Hill and Wilcza Góra, Sudetes, SW Poland. The two outcrops are 8 km apart. The xenoliths are hosted by basanitic intrusions which belong to the Central European Volcanic Province (CEVP). All samples were examined for accessory minerals: apatites, sulfides and micas using polarized- and reflected light and analyzed by EPMA.

The apatites from Wołek occur within basanite-derived veins, pyroxenite veins and melt pockets. The apatite from thin glass+cpx+fsp+ap+sulfides basanitic veins occurs as euhedral acicular- or needle-eye shaped crystals up to 50 μm long with well-developed sieve structure. The apatites spotted in pyroxenite veins in wehrlite and within the melt pockets occur as euhedral grains several μm long. None of Wołek apatites was analyzed by EPMA due to their small dimensions. Apatites from Wilcza Góra occur interstitially in ol+opx+glass peridotites and within glass+ol+cpx+spl+ap melt pockets as subhedral and anhedral polygonal grains, 100-500 and 200 μm long, respectively. Apatites from both populations seem to be in microstructural equilibrium with px and ol, but they also border with glass and show well-developed sieve structure. All analyzed apatites were classified as hydroxyl-fluor apatites. They have low Cl (0.34-0.45%) and high F content (1.3-2%) as well as low Sr content (1700-2500 ppm). Such a composition is characteristic for apatites of magmatic origin and may indicate crystallisation from a carbonatitic magma component (O'Reilly, Griffin 2000) or metasomatic fluids of crustal origin/influence.

Sulfides, found only in Wołek xenoliths, occur in glassy basanite-derived veins, melt pockets and cracks in olivine grains. They occur as anhedral nodular grains, from several to 100 μm long, with many embayments, cracks and possible sieve structure. They form monomineral blobs of ccp, pn and po as well as clusters and submicroscopic intergrowths of all three phases. EPMA analyses of the latter yielded difficult to interpret S-Ni-Fe-Cu compositions with highly varying contents of each element (23-34% Ni, 13-21% Cu, 12-22% Fe) which may be the result of a few intergrown phases being simultaneously activated by the electron beam. The mineral assemblage of pn, ccp and po may be the result of monosulfide solid solution (mss) exsolution. The formation of mss can be attributed either to late-magmatic metasomatism of basanites and peridotites or a high-temperature subsolidus process between primary sulfides and silicates (Stone et al. 1989).

Ti-Ba-rich phyllosilicates were found within px+fsp+foid+glass melt pockets in Wołek xenoliths. They occur as colourless plates, several to 70 μm long, with a distinct cleavage. Usually, they contain 6-7% TiO_2 and 4-5% BaO. This composition may indicate the existence of a metasomatic, as yet unnamed, mica or highly Ba-enriched phlogopite.

Similar micas have been reported from Tariat (Mongolia) xenoliths as a product of phl breakdown and from Tok (Siberian craton) xenoliths with no structural evidence for such a process (Ionov et. al. 2006). Ti-Ba-rich phases from Wołek resemble those from Tok, though a thorough comparison with the Wołek phlogopites remains to be done.

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Textural and chemical varieties of garnets in the pegmatites from Piława Górna quarry (Dolnośląskie Surowce Skalne S.A.), Góry Sowie Block, southwestern Poland

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Texturally diversified garnets are common rock-forming minerals in the pegmatite veins ("Julianna", "TRIO", "subTRIO", and "Lithium") exposed in the Piława Górna quarry. Garnets occur mainly in the pegmatite zone rich in graphic- and blocky microcline with irregularly distributed muscovite, and tourmaline aggregates. Some quartz cores are also intergrown with garnets which may reach up to 5 cm in diameter. The color of the garnets ranges from dark brown, through reddish-brown to bright orange. The garnets commonly form automorphic crystals and/or aggregates together with tourmaline, muscovite, beryl and columbite. The dodecahedron and trapezohedron are the most common crystal forms characterising this garnet type in all of the pegmatite veins from Piława Górna. Symplectitic intergrowths with quartz, potassium feldspar and muscovite represent the second garnet type. They form oval patches which range from 1-10 cm in diameter.

The chemical composition of the garnets is highly diversified. MnO and FeO contents vary from 44.71-11.68 wt% and from 43.49-1.47 wt%, respectively. Y_2O_3 ranges from 1.13-0.04 wt%. The Mn-rich garnets consist predominantly of the end-members spessartine (0.96-0.27), almandine (0.63-0.05), grossular (0.22-0.01), andradite (0.14-0.01) and pyrope (0.04-0.01). The blythite ($Mn_3Mn_2(SiO_4)_3$), calderite ($Mn_3Fe_2(SiO_4)_3$) and skiagite ($Fe_3Fe_2(SiO_4)_3$) end-members were also calculated in garnets from highly fractionated pegmatites ("Lithium" pegmatite vein); they range between 0.43-0.01, 0.24-0.02, and 0.19-0.01, respectively.

The chemistry of garnets is commonly used as a monitor of fractionation of pegmatitic melts (London 2008). The composition of the investigated garnets changes progressively from Fe–rich cores to more Mn–rich rims. Anomalous Mn-rich garnets in which the spessartine end-member reaches up to 96 mol.% occur in the more fractionated "Lithium" pegmatite vein. This Mn-rich fractionation trend probably reflects crystallization of Fe-rich minerals, mainly biotite at an early stage, followed by Fe-rich tourmaline.

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Mineral assemblages in melt pockets from mantle xenoliths, Wołek Hill (SW Poland)

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Melt pockets, known as patches or blebs, are discrete bodies in intergranular spaces of hosting peridotite and are very common in mantle xenoliths worldwide. They contain glass, clinopyroxene, spinel, amphibole, plagioclase, carbonate and olivine and orthopyroxene. The latter two minerals are represented by two generations, the first being partly resorbed. In Poland, melt pockets were recognized from a number of outcrops, for example, Łysanka, Lutynia (Bakun-Czubarow, Białowolska 2005, Matusiak-Małek et al. 2010). The present paper is the first description of the mineralogical composition of melt pockets in peridotite xenoliths from Wołek Hill.

Wołek Hill is an example of Cenozoic volcanism in Lower Silesia. It is localized about 8km south from Złotoryja, near the village of Różana. The host rock, reclassified as basanite (Nowak, Muszyński 2009), contains a great number of mantle xenoliths – mostly harzburgites, but also dunites and wehrlites. The melt pockets presented were found in harzburgites and, in one case, dunite.

The main minerals in the xenoliths are olivine (Ol; Fo 91-92, Ca content < 200 ppm) and orthopyroxene (Opx; Mg# 90-91). Clinopyroxene (Cpx) and spinel (Spl) occur in melt pockets or in spinel-pyroxene clusters. In the samples described, amphibole (Amph) occurs only as intergrowths in Opx. In majority of the xenoliths, the melt pockets have no contact with the host basanite; only in three cases were they found to be connected to the basanite by sharp veins with Cpx (Mg#78-80, Al 0.48, Ca 0.89 apfu), feldspar, apatite, sulfide and accessory mica.

Melt pockets are divided into two textural types: smaller (ca 0.3-1.6 mm) and larger (ca 3-5 mm). Smaller rounded, ellipsoidal or irregular pockets occur in most samples and are commonly linked. Larger pockets, occurring only in four peridotites with protogranular structure, are rounded and isolated. The crystal sizes of minerals in melt pockets vary from 20-400 μm. The mineralogical composition is dominated by Cpx with variable chemical composition (Mg# 87-93; Al 0.04-0.21 apfu; Ca 0.76-0.80 apfu). Cpx in large melt pockets shows spongy texture. Spinel crystals (Cr# 44-69; >75) in melt pockets are spongy or skeletal in texture. Ol and Opx occur mainly as non-resorbed fragments of main peridotite phases; the second generation of Ol is enriched in Mg and Ca (Fo rises to 93, Ca > 800 ppm). Feldspars, feldspathoid, glass, carbonates and Ba micas also occur in melt pockets.

The origin of melt pockets in Wołek Hill xenoliths is at least threefold. They are (1) products of interactions with host basanites, (2) remnants from decompression melting and (3) the products of amphiboles disintegration.

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Lithium pegmatite from the DSS Piława Górna mine, Góry Sowie Block, southwestern Poland

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Li-bearing mineralization is almost completely unknown in Poland. Single occurrences of lepidolite in pegmatites of the Karkonosze and Strzegom granite are mentioned in old mineralogical literature. However, none of these is corroborated by more precise modern studies. To date, there are two valuable indications of Li-bearing mineralization in the pegmatites of the Góry Sowie gneissic complex. These are ferrisicklerite, $Li_{1-x}(Fe,Mn)PO_4$, forming lamellar intergrowths with graftonite, sarcopside, Ca-beusite, staněkite, alluaudite and numerous others phosphates in a pegmatite near Świdnica (Pieczka et al. 2003) and green elbaite found in the vicinity of Gilów (Pieczka et al. 2004).

In this context, relatively large pegmatite bodies with abundant Li-bearing mineralization exposed in the DSS Piława Górna mine in early 2010 are valuable corroboration of the advanced geochemical evolution of a parental anatectic melt and high-Li fractionation. The pegmatites, representing the rare-element class in the classification of Černý and Ercit (2005), contain abundant tourmaline with varying coloration from black, to bluish, greenish, yellowish, pinkish, reddish and colorless that is intermediate between schorl, dravite, elbaite, olenite, rossmanite and liddicoatite end-members. They also contain pink lepidolite and pollucite, associated with Nb-enriched cassiterite, spessartine, fluorapatite, zircon and highly-evolved columbite-(Mn) and tantalite-(Mn).

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Mn-Fe fractionation in tourmalines from pegmatites in the DSS mine at Piława Górna, Góry Sowie Block, southwestern Poland (preliminary data)

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Black tourmaline is a common component of pegmatites in the Góry Sowie gneissic complex. Such tourmaline usually corresponds to Mg- and Al-bearing schorl with a small amount of Fe^{3+} not exceeding 5% of the total Fe (Pieczka 1996). In the summer of 2009, an intergrowth of small tourmaline crystals with black cores overgrown by thin greenish rims was found in a pegmatite at the Piława mine. Core tourmaline is represented by schorl with anomalously high Fe contents increasing outward from 12.8-14.8 wt% FeO (1.79-2.11 Fe apfu), decreasing Mg from 1.7 to 0.5 wt% MgO (0.42-0.11 Mg apfu) and almost constant Al (33.3-34.3 wt% Al_2O_3). In the outermost irregular zone of the core, Mn clearly increases reaching 0.43 wt% MnO (0.06 Mn apfu) in relation to 0.21 wt% MnO inside the crystal. The green rim with a few tiny contact zones on the core/rim boundary overgrows the crystal core. Within those zones, a marked progressive increase in Mn (1.2-2.5 wt% MnO, 0.17-0.35 Mn apfu) and Li (0.00-0.34 wt% Li_2O, 0.00-0.23 Li apfu) is associated with only a slight increase in Al (35.5-36.2 wt% Al_2O_3), a distinct decrease in Fe (11.1-8.8 wt% FeO, 1.56-1.22 Fe apfu) and Mg (1.00-0.23 wt% MgO, 0.25-0.06 Mg apfu). The green rim is richest in Mn (3.8 wt% MnO, 0.53 Mn apfu), Li (0.38 Li_2O, 0.26 Li apfu) and Al (36.9 wt% Al_2O_3, 7.22 ^{VI}Al apfu) and poorest in Fe (6.6 wt% FeO, 0.91 Fe apfu) and Mg (0.16 wt% MgO, 0.04 Mg apfu). A small deficiency in Si, supplemented by Al, occurs only in the core tourmaline. For all the varieties, Na > X-vacancy > Ca at the X site and OH > O/F at the W site. Fluorine concentrates in successive zones outward from 0.0 to almost 0.9 wt%. These compositions indicate progressive variation in crystallizing tourmaline from Mg- and Al-bearing to Al-bearing schorl in the core, to intermediate members between schorl and Mn-bearing olenite in the contact zones, and to Fe- and Mn-bearing olenite in the rim, with a progressive increase in Mn-Fe fractionation expressed by Mn/(Mn+Fe) varying from 0.02-0.03 in the core, 0.10-0.22 in the contact zones and 0.37 in the rim.

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Nb-Ta minerals in pegmatites in the DSS mine at Piława Górna, Góry Sowie Block, southwestern Poland

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Pegmatites in the Góry Sowie gneissic block are known from almost 150 years. In the 19th century, they were mined in numerous localities (e.g., Owiesno, Różana, Piława, Bielawa, Kamionki) as a feldspar-bearing material. At that time, German mineralogists mentioned the presence of *columbite*, occurring rarely in the form of thin laths up to 5 milimeters long in a pegmatite near Piława (Romer 1864; Roth 1867; Traube 1888; Hintze 1933; *fide* Lis, Sylwestrzak 1986). However, many years later, Mikuszewski at al. (1976) concluded that the Góry Sowie metamorphism was not sufficient for the formation of zoned pegmatite bodies enriched in trace elements including Li or Nb.

Some large dikes and veins of pegmatite containing Nb-Ta minerals have been exposed in the DSS mine at Piława Górna during the mining of migmatite and amphibolite as aggregate material. The primary Nb-Ta phases recognized here include ishikawaite, $(U,Fe,Y,Ca)(Nb,Ta)O_4$, samarskite $(Y,Fe^{3+},Fe^{2+},U)(Nb,Ta)O_4$, calciosamarskite, $(Ca,Fe^{3+},Fe^{2+},U,Y)(Nb,Ta)O_4$, polycrase-(Y), $(Y,Ca,Ce,U,Th)(Ti,Nb,Ta)_2O_6$, ixiolite, $(Ta,Nb,Sn,Mn,Fe)O_2$, columbite-(Fe), $(Fe,Mn)(Nb,Ta)_2O_6$, tantalite-(Fe), $(Fe,Mn)(Ta,Nb)_2O_6$, columbite-(Mn), $(Mn,Fe)(Nb,Ta)_2O_6$, tantalite-(Mn), $(Mn,Fe)(Ta,Nb)_2O_6$, and fersmite, $(Ca,Ce,Na)(Nb,Ta,Ti)_2(O,OH)_6$. Secondary Nb-Ta minerals are represented by members of the pyrochlore group such as pyrochlore, $(Na,Ca)(Nb,Ta)_2O_6(O,OH,F)$, yttropyrochlore, $(Y,Ca,U)(Nb,Ta,Ti)_2O_6(O,OH)$, uranpyrochlore, $(U,Ca,Ce)_2(Nb,Ta)_2O_6(OH,F)$, microlite, $(Na,Ca)(Ta,Nb)_2O_6(O,OH,F)$, plumbomicrolite, $(Pb,Na,Ca)(Ta,Nb,Ti)_2O_6(O,OH,F)$, bismutomicrolite, $(Bi,Ca)(Ta,Nb,Ti)_2O_6(O,OH)$, betafite, $(Ca,U)(Ti,Nb,Ta)_2O_6(O,OH)$ and yttrobetafite, $(Y,Ca,U)(Ti,Nb,Ta)_2O_6(O,OH)$.

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Selected technical parameters of travertine, limestone and marble and their control on resistance to weathering

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Petrographic and physical features of rocks constrain their resistance to weathering. These features are very important for building stones, in particular nowadays, with increasing atmospheric pollution.

In our study, physical parameters were measured, comparatively, in three types of carbonate rocks which are widely used in the Polish stone market: travertine (Iran), limestone (Morawica, Central Poland) and marble (Marianna, Stronie Śląskie, SW Poland). This study was an introduction to the laboratory modelling of chemical weathering of the carbonate rocks in acid solutions imitating acid rains (Prell 2008).

Based on optical polarizing microscopy, X-ray diffraction and differential thermal analyses, the only major component in the rocks studied is calcite, with negligible traces of quartz and other constituents.

The physical parameters, important for the resistance of the rocks to chemical weathering, were determined following the EU norms: water absorption (EN 13755:2001), porosity (PN-EN 1936:2001) and resistance to salt crystallization (PN-EN 12370:2001).

For water absorption measurements, 50x50x50 mm cubes were used. For porosity and resistance to salt crystallization, following the norms, smaller 40x40x40 mm cubes were used with those for salt-resistance measurements having one face polished. The different measurements were performed on six samples of each rock type.

Not surprisingly, the highest porosity occurs in the travertine (8.8%), much lower in the limestone (6.1%) and lowest in the marble (2.8%). Unexpectedly, however, the highest water absorption is not in the travertine (0.52%) but in the limestone (1.61%), and lowest in the marble (0.04%). The results suggest that the pores in the travertine are highly macroporous with very low water absorption potential or that they are not interconnected but isolated and, thus, inhibit water permeability. In contrast, the limestone is apparently microporous and its small pore throat diameter can be responsible for the capillary uptake of water.

The resistance to salt-crystallization damage is high for the limestone and marble (neglected weight loss after 15 cycles), whereas it is significantly lower for the travertine (weight loss of c. 0.5%). The limestone and marble cubes had only matt surfaces after the experiment, whereas the travertine samples had often lost their edges and corners.

The travertine was also found to be the least resistant to chemical weathering in our laboratory modelling. This feature, together with the high water absorption and resistance to salt crystallization damage, are important factors to be taken into account when using the carbonate rocks, in particular travertine, in an external setting exposed to polluted atmospheric conditions.

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Niobium-tantalum minerals in the Skoddefjellet NYF pegmatite, Svalbard Archipelago, Norway: primary versus secondary assemblage

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The first documented occurrence of Nb-Ta mineralization in a granitic pegmatite from the Svalbard Archipelago, Arctic Caledonides, and the relationships between primary and secondary Nb,Ta-bearing phases, are discussed. The Skoddefjellet granitic pegmatite dyke, located in southwest Spitsbergen (Wedel Jarlsberg Land), is hosted by paragneisses and mica schists of the Isbjørnhamna Group. The NYF pegmatite is characterized by enrichment in Nb, U, Zr, Y, REE and Pb, low Zr/Hf (~8-10), and Nb/Ta (~8-12). The pegmatite displays weak zoning at the outcrop scale, with border and blocky zones, a quartz core and a zone of fine-grained saccharoidal albite. The main minerals are quartz, K-feldspar fine-grained albite, muscovite and biotite. Besides the Nb-Ta phases, minor to accessory minerals are: beryl, spessartine-almandine garnet, gahnite, minerals of the gadolinite group, zircon, thorite, uraninite, fluorapatite, monazite-(Ce), xenotime-(Y), keivyite-(Y), allanite-(Ce), REE-bearing epidote, clinozoisite, parisite-(Ce), synchysite-(Ce), bastnäsite-(Ce), pyrite, galena, acanthite, calcite and barite. Columbite-(Fe) and columbite-(Mn) (locally enriched in Ti, Y, Sc and Ca) and Nb,Ta,Y-bearing titanite (≤3.8 wt% Nb_2O_5, ≤1.9 wt% Ta_2O_5, ≤2.9 wt% Y_2O_3) represent the primary magmatic Nb-Ta minerals. Columbite group minerals occur as large individual crystals up to 0.5 cm in size or as relicts of grains partly replaced by fersmite or pyrochlore-group minerals. Titanite forms crystals up to several mm in size, located in K-feldspar and usually in association with allanite-(Ce) and apatite. It locally shows fine oscillatory- and sector zoning in BSE (caused by Nb, Ta, Al and Y). The secondary assemblage comprises Nb,Ta-bearing rutile (≤23 wt% Nb_2O_5, ≤1.7 wt% Ta_2O_5), ilmenite, fersmite and pyrochlore-group minerals including yttropyrochlore, plumbopyrochlore, yttrobetafite and plumbobetafite. Internal zoning of columbite-group minerals is expressed by a distinct rimward increase in Mn/(Mn+Fe) from 0.07 to 0.83 and the low Ta/(Ta+Nb) of 0.03-0.10, suggesting an alkaline environment and increasing fluorine activity during the pegmatite evolution. Nb-Ta titanite precipitated also during the magmatic stage. The occurrence of Y,REE,U,Th,Pb-rich members of the pyrochlore group, and of fersmite, documents an extensive hydrothermal overprint of the Skoddefjellet pegmatite. Notably, the formation of Nb,Ta-bearing rutile and ilmenite seems to be a product of Nb,Ta-bearing titanite alteration.

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Lateral variation of lithospheric mantle beneath SW Poland

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The Cenozoic rifting event formed the Ohře (Eger) Rift with voluminous volcanic sequences in the NW part of the Bohemian Massif. Miocene lavas with abundant mantle xenoliths occur in SW Poland at the NE prolongation of the Rift (e.g., Księginki nephelinite). The single ca 4-4.5 Ma xenolith-bearing eruptions occur to the SE of the Rift (Kozákov and Lutynia basanites), which allows the comparison of lithospheric mantle located outside the rifted area with that located close to the rift and the assessment of possible changes in the mantle during the time span of ca 20 Ma. The mantle peridotites from the Księginki are affected by silicate-melt induced cryptic metasomatism resulting in enrichment of clinopyroxene in light REEs and show similar equilibration temperatures of 1000-1100ºC. Pyroxenite cumulates with similar trace element characteristics are common in the Księginki nephelinites. The composite xenoliths show that pyroxenites form the veins in peridotites. Therefore, the lithospheric mantle beneath the northern termination of Ohře Rift was affected by silicate melt metasomatism and thermally rejuvenated, and its lithology was modified by addition of pyroxenitic veins. The modification was contemporaneous with volcanism (Puziewicz et al. submitted).

The peridotite xenoliths occurring in the 4 Ma Kozákov basanites (Czech Republic, ca 25 km SE from Ohře Rift margin) equilibrated at temperatures from 680-1065ºC (Christensen et al. 2001). The 4.5 Ma basanites from Lutynia (SW Poland, ca 170 km ESE from the Ohře Rift) contain peridotites which equilibrated at 960-1000ºC which contain post-garnet spinel-clinopyroxene symplectites (Matusiak-Małek et al. 2010). The clinopyroxenes occurring in Lutynia peridotites preserve three different kinds of REE pattern, all LREEs enriched. These data suggest that the lithospheric mantle occurring outside the Ohře Rift was not completely homogenized during volcanism, and that the record of older events is still preserved.

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New data on some silver and mercury minerals from the Miedzianka-Ciechanowice deposit (Rudawy Janowickie Mts, Western Sudetes, Poland) – preliminary report

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Polymetallic veins containing rich mineralization (including native silver forming sheets up to 30 cm in diameter, proustite, acanthite, and others) were exploited in the "Friederike Juliane" mine from 1781-1849. Samples were collected on the dumps of the former "Friederike Juliane", "Neu Adler" and "Feliks" mines. Mineral chemical compositions were determined by electron microprobe.

Silver in the samples from the "Friederike Juliane" mine forms wires, dendrites and inclusions in white-pink barite accompanied by minor calcite. The silver is characterized by its high purity. Only small amounts of mercury (up to 0.73 wt% Hg), cadmium (0.49-0.77 wt% Cd) and arsenic (0.12-0.29 wt% As) were found. Small grains of silver sulfide surround the wires of native silver. This mineral is also pure. The contents of its main constituents are slightly variable ─ 85.75-87.32 wt% for Ag and 13.20-14.87 wt% for S. Only a small admixture of cadmium (0.39-0.67 wt%) is present.

Stromeyerite and silver amalgams were identified in the samples from the "Neu Adler" mine. The stromeyerite forms thin veinlets cutting massive bornite-chalcocite ore. In some cases, it coexists with silver amalgams. Silver and copper contents in the stromeyerite vary from 53.54-56.26 wt% Ag and from 28.24-32.08 wt% Cu, respectively The average empirical formula of the stromeyerite is $Ag_{1.06}Cu_{1.02}S$.

Besides the bornite-chalcocite ore, löllingite may also act as the matrix for silver amalgams. The silver amalgams in löllingite form fine, droplet-like, irregularly-arranged segregations up to 5 μm in size. In the bornite-chalcocite ore, the amalgams form irregular aggregates up to 0.3 mm in size. They usually occur at the chalcocite-bornite border. In some cases, they are associated with the segregations of stromeyerite. On BSE images, a mosaic-like structure reflecting the variable chemical composition of the aggregates can be observed. Most of the analyzed phases correspond, in their chemical composition, to eugenite with the empirical formula $Ag_{11.0}Hg_{2.05}$. This mineral is associated with an amalgam belonging to the $Ag_{6.10}Hg_1$-$Ag_{17.43}Hg_1$ series and with native silver of high mercury content (4.28-4.45 wt% Hg). Hessite was found among quartz-chalcopyrite-tetrahedrite veins, fragments of which were collected on the dumps of the "Feliks" mine. This mineral forms fine segregations up to 5 μm in size in massive tetrahedrite. The empirical formula of the hessite from the "Feliks" mine is $Ag_{2.01}Te_{0.97}S_{0.02}$.

The silver-rich mineralization belongs to the low-temperature ore parageneses of the polymetallic ore veins in the Miedzianka-Ciechanowice deposit.

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Secondary uranium minerals from the Miedzianka-Ciechanowice deposit (Rudawy Janowickie Mts., Poland)

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The oxidation zone of the Miedzianka-Ciechanowice polymetallic deposit contains a rich palette of supergenic minerals. Up to now, about 60 secondary phases have been recorded there. Among them, some secondary uranium minerals also occur. Identification of these phases was based on both PXRD and EMPA analyses.

A diverse association of secondary uranium minerals was found at the dumps of the Miedzianka mine. Within it, torbernite forms green tabular crystals that rapidly become cloudy due to loss of crystallization water. The copper content in the mineral varies from 0.24-0.65 apfu. This element is associated with small admixtures of Ca (up to 0.03 apfu) and potassium (0.02-0.05 apfu). The phosphorus content varies from 0.81-1.39 apfu. Its deficiency is compensated by arsenic which is present in the varying amounts from 0.49-0.86 apfu. The analysed mineral belongs to both the torbernite-metatorbernite-chernikovite- and torbernite-metatorbernite-zeunerite-metazeunerite solid solutions. Torbernite coexists with bassetite. The latter mineral occurs as aggregates of dark brown, thin, tabular crystals replacing torbernite. The analysed bassetite constitutes an intermediate member of the bassetite-autunite-saléeite series. The amount of Fe, Ca and Mg in the Miedzianka bassetite varies from 0.35-0.83, 0.12-0.50 and 0.02-0.57 apfu respectively. The high content of Cu (0.19 apfu on average) is likely due to fine relics of torbernite in the bassetite. Among the bassetite aggregates, tiny (up to 50 μm) saléeite segregations occur. These are distinctly younger than the bassetite. The Mg content in saléeite varies from 0.39-0.77 apfu, the Fe content from 0.02-0.46 apfu and that of Ca reaches up to 0.38 apfu. The last mineral of the paragenesis is parsonsite. Its radiating aggregates, up to 200 μm in diameter, grow in bassetite or torbernite. The content of lead in the parsonsite ranges from 1.62-2.11 apfu.

Another secondary uranium-mineral association, from the former Miedzianka mine, is one dominated by silicates of U. In this case, the main mineral is uranophane for which the Miedzianka-Ciechanowice deposit is the holotype locality. Three morphological types of uranophane were distinguished. The first type forms radiating or tuft-like aggregates of thin needle-like crystals. The second type occurs as bright yellow crystals of tabular habit. The most common uranophane is compact, forming cryptocrystalline aggregates of greasy lustre that represent pseudomorphs after uraninite. The empirical formula of this third uranophane variety is $(Ca_{0.90}K_{0.04}Fe_{0.02}Pb_{0.01}Bi_{0.01})_{\Sigma 0.98}(UO_2)_{2.15}(SiO_3OH)_2 \cdot 2.37H_2O$ – based on EMPA analyses. Uranophane is associated, among others, with kahlerite $(Fe(UO_2)_2(AsO_4)_2 \cdot 10\text{-}12H_2O)$, which forms spherical aggregates composed of thin, tabular crystals occurring in the cracks cutting cryptocrystalline uranophane. Another U silicate encountered in the dumps of the Miedzianka mine, is an unspecified species of composition close to cuprosklodowskite. It occurs as green, thin covers or spherical aggregates composed of short-prismatic crystals up to 5 μm in size that cover the highly-altered uraninite.

The U silicates also coexist with unspecified U minerals rich in lead (8.32-14.55 wt% PbO) and bismuth (15.64-25.65 wt% Bi_2O_3) of the uranyl oxide- or hydroxide groups.

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Geochemical constraints on the provenance and depositional setting of metasedimentary rocks from the Bystrzyckie Mts. Crystalline Massif, Sudetes, SW Poland

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The Bystrzyckie Mts Crystalline Massif forming the western flank of the Orlica-Śnieżnik Massif (OSM) is composed of large orthogneiss bodies that are mantled by a metamorphosed volcano-sedimentary series comprising mainly mica schists, paragneisses, basic and acid metavolcanics and marbles. Most probably, the protoliths of the paragneisses and mica schists were arkosic sandstones and mudstones, respectively. Though its age is unknown, most rocks of the volcano-sedimentary series cropping out in the Bystrzyckie Mts are believed to be of Latest Neoproterozoic-Early Palaeozoic age on basis of micropaleontological findings. Basic metavolcanics were described as MOR-type basalts that originated during a Cambro-Ordovician episode of extension and disintegration of the northern periphery of Gondwana or as formed in a back-arc setting related to an unspecified subduction episode. Because the ambiguous chemistry of the metabasic volcanics does not allow an unequivocal interpretation for the tectonic environment of their emplacement, this study is focused on the provenance and tectonic setting of deposition of the supracrustal series cropping out in the Bystrzyckie Mts.

Major and trace element data for the investigated clastic sediments are compatible with an acidic to intermediate source. It is documented by proportions of Cr/Th, La/Sc and Sc/Th. This conclusion is, furthermore, reinforced by low values of Cr/V, Y/Ni and a low abundance of TiO_2 and Ni. On spider diagrams, normalized to upper continental crust composition (UCC), the investigated rocks show a pronounced negative Nb-Ta anomaly typical of acid volcanics that were generated in a suprasubduction tectonic setting. The chondrite normalised patterns of the investigated metasediments show $\Sigma REE = 160 \pm 45$ ppm, strong LREE enrichment, nagative Eu anomalies as well as a flat HREE pattern manifested by mean values of $La_N/Yb_N = 8.73 \pm 3.39$, $Gd_N/Yb_N = 1.27 \pm 0.30$ and $Eu/Eu^* = 0.66 \pm 0.11$. These indicators are intermediate between Active Continental Margin (ACM) and Continental Island Arc (CIA) tectonic settings. Furthermore, on several diagrams such as Sc – Th – Zr/10, Th – La – Sc, La/Sc – Ti/Zr and Fe_2O_3+Mgo – TiO_2, the samples fall mainly within ACM or CIA fields indicating their deposition in a sedimentary basin developed in a supra-subduction setting.

Assuming that all the metavolcanics and metasediments of the supracrustal series were formed in the same depositional basin, it is hypothesized that the most probable tectonic setting for their emplacement is a back-arc basin. Thus, if the supracrustal series of the Bystrzyckie Mts is actually of Early Palaeozoic age, rifting and disintegration of Gondwana at the onset of the Rheic Ocean may have resulted from back-arc spreading. Otherwise, the geochemical record revealed by the supracrustal series relates to the latest Proterozoic subduction beneath the Gondwana margin.

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Textural variation of Permian rhyolites of the North-Sudetic Basin

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Textural analysis, on a thin section to hand-specimen scale, is a powerful tool for deciphering the origins of volcanic rocks in ancient successions, especially when post-emplacement processes such as devitrification, alteration, erosion, and limited exposure, obscure the primary characteristics (e.g., Paulick, Breitkreuz 2005). The Permian rhyolitic sequence cropping out north of Świerzawa in the North-Sudetic Basin in SW Poland is an example of an extensive (8.5 km x 3.5 km), thick (~ 200 m) and lithologically monotonous volcanogenic complex which is not open to easy palaeovolcanological interpretations. The vent(s) location, emplacement processes and internal structure of this complex have been characterized in only a general way to-date (Kozłowski, Parachoniak 1967). This paper provides some new observations on rocks from the western part of the sequence between the Kaczawa River and the village of Sokołowiec.

Rhyolites, and underlying 'rhyolitic tuffs' are two lithologies mapped there. The rhyolites are massive to platy-jointed, locally brecciated, quartz- and feldspar-phyric with a microcrystalline groundmass of alkali feldspars and quartz. The petrographic variation is mainly expressed in the groundmass textures. The groundmass is usually felsitic and heterogeneous, with pale-brown, relatively coarse-grained patches and darker, finer-grained patches. The patches range from tenths of a millimetre to a few millimetres in size. Less common are banded to laminated rhyolites, characterized by the alignment and alternation of paler- and darker streaks and bands. Spherulitic- and perlitic rhyolites are rare but characteristic rocks. The 'rhyolitic tuffs' are very poorly exposed and commonly strongly altered into a mixture dominated by clay minerals, mainly illite. Locally, agate mineralization occurs. The best exposure at Owczarnia Hill, however, comprises a few metres of bedded rhyolitic sandstones to conglomerates/breccias. Their main components are felsitic and spherulitic-rhyolite fragments and broken quartz- and feldspar crystals.

The rhyolites may largely represent microcrystalline lavas typical of the more slowly-cooled internal parts of thick rhyolitic lava flows or domes. The banded, spherulitic and perlitic rhyolites, however, are typical of the outer parts of lava flows which underwent rapid quenching into glass and, later, variable devitrification. The rocks from Owczarnia Hill may be of pyroclastic origin (small-volume block- and ash-flow deposits and related fall deposits resulting from lava dome/flow collapse?) or may represent volcaniclastic/epiclastic deposits related to the erosion of rhyolitic lavas.

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Geology of the Julianna pegmatite vein system from the Piława Górna quarry (Dolnośląskie Surowce Skalne S.A.), Sowie Mts Block, SW Poland

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Granitic pegmatites, named the Julianna pegmatite vein system, were discovered during mining works in the Piława Górna Quarry in 2007. They form a system of up to 4 m thick veins cutting migmatitic gneisses and amphibolites that can be followed for up to 50 m in a vertical cross section. The pegmatites are developed as a number of anastomozing veins with broadly varying dips in the root part and which pass upwards into 3 main well-defined steeply-dipping bodies with the overall NE-SW strike. Subordinate subhorizontal apophyses bifurcate from the main veins. The pegmatite/country rock contact is in places marked by a biotite envelope a few centimetres thick. The pegmatites are internally zoned with an idealized zone sequence as follows: (i) thin and discontinuous fine-grained border zone, (ii) coarse- to very coarse-grained pegmatite with elongated biotite megacrysts, (iii) graphic- to blocky microcline with irregularly distributed muscovite-, tourmaline- and garnet-quartz intergrowths, (iv) quartz core. The apophyses are zoned asymmetrically with individual zones strongly reduced or missing in the hanging wall parts. Muscovite- or albite-dominated replacement regions were identified in places.

The rock forming minerals are microcline, albite, quartz, biotite, muscovite, tourmaline-group, almandine-spessartine garnets and beryl. Accessory phases include columbite-group and other Nb-Ta minerals, zircon, monazite, xenotime, fluorapatite, pyrite, ilmenite, uraninite, arsenopyrite, bismuth and bismuthinite. Bavenite, clinochlore, stilbite, chabazite, bismite, bismutite and goethite were identified as secondary minerals. Large scale symplectic textures of quartz-feldspar, tourmaline-quartz and garnet-quartz are a characteristic feature of the Julianna pegmatite system. The Julianna pegmatite system belongs to the rare-element class (Černý, Ercit 2005).

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Topaz, lepidolite and phenacite-bearing pegmatite from Żółkiewka quarry, Strzegom-Sobótka granite massif, Lower Silesia, SW Poland

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The Strzegom-Sobótka Variscan granitic massif is famous for intragranitic miarolitic pegmatites of MI REE subclass with NYF signature. However Be- and Li-bearing phases are regarded there as rare and topaz as extremely rare.

A miarolitic pegmatite with abundant topaz, lepidolite and phenakite was discovered in the Żółkiewka I quarry near Strzegom in April 2010. The cavity, ~1 m long and 30 cm high, is the largest of miaroles occurring in a flat-lying irregular pegmatitic vein. It displays a typical textural- and mineralogical zoning from an outermost border aplite, through a thin biotite-rich zone, quartz-feldspar graphic intergrowths and blocky microcline to euhedral crystals lining the cavity walls. Accessory W-Ta-bearing columbite(-Mn), cassiterite and zircon with thorite inclusions accompany rock-forming amazonite-like microcline, lepidolite and clinochlore in the blocky microcline zone. Cavity-filling crystals include quartz (*Qtz*), microcline (*Mc*), lepidolite (*Lpd*), muscovite (*Ms*), topaz (*Toz*), phenakite (*Phk*), tourmaline (*Tur*), albite (*Ab*), fluorite (*Fl*), stilbite (*Stb*), chabazite (*Cbz*) and montmorillonite (*Mnt*). Pinkish *Lpd* forms ≤3 cm pseudohexagonal plates with *Ms* rims. Creamy yellow short prismatic *Mc* crystals are ≤6 cm long. Two varieties of *Toz* are present: colourless isometric or prismatic ≤1 cm long crystals and brownish and bluish short prismatic from 2 cm to 5-6 cm long individuals. Small crystals of *Toz* grow on *Lpd*, *Mc* and *Qtz*. Colourless or whitish *Phk* forms combinations of very short trigonal prisms and rhombohedra. Up to 10 cm long prismatic *Qtz* is strongly zoned. Earliest smoky generations often enclose *Toz* and *Phk* and are overgrown by colourless *Qtz* with phantom structures marked by tiny inclusions. Up to 0.5 cm long greenish or brownish black needles and fibres of *Tur* (schorl-dravite) grew on *Mc*, *Lpd*, *Toz*, *Phk* and early *Qtz*. They also form inclusions in late *Qtz* and *Ab*. *Ab* is present as colourless platy cleavlandite. Bluish-violet and colourless *Fl* forms combinations of distorted octahedra with subordinate cube faces and its faces show a rather dull luster on etched faces. A similar dull luster is observed on *Cbz* etched surfaces. The minerals crystals are often covered by a rosy-white or slightly olive-green *Mnt* crust. The crystallization order in the miaroles was as follows: *Qtz* + *Mc* + *Lpd* ➔ *Qtz* + *Toz* + *Lpd* ➔ *Qtz* + Phk ➔ Qtz + *Ab* + *Tur* ➔ *Ms* + *Fl* + *Cbz* + *Stb*➔ *Mnt*.

In addition to rock-forming Qtz, Mc and Ab, Toz, Lpd and Phk are essential constituents of the pegmatitic assemblage. Together with accessory W-Ta-bearing manganocolumbite, they point to high fractionation of the pegmatite resulting in Li-, Be- and Ta-enriched melt. Out of 6-7 other smaller cavities in the same vein over a distance of ca 5 meters, this assemblage was observed in one and Toz + Lpd without Phk in another. This may suggest that such highly evolved fluids formed only locally, even within a single system of interconnected miaroles. It may also suggest some immiscibility of geochemically specialized hydrothermal fluids.

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The chemical composition of apatite in teschenite from the Cieszyn area and in granite from the Western Tatra Mts

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Apatite is a common accessory mineral in most igneous rocks. That mineral is a carrier of halogens, sulfate- and carbonate-ions, Sr and REE. Apatite grains from two geochemically different types of rocks were separated and analysed by means of SEM, EMPA and LA-ICP-MS.

The first type of apatite came from the teschenite Puńców sill (the Cieszyn magma province). These rocks contain up to 1.2 vol.% of apatite in the form of needle-like crystals enclosed in kaersutite and are associated with interstitial plagioclases, nepheline and analcime. The apatite crystals are 0.2 to 0.8 mm long and 0.06-0.22 mm wide. The greatest elongation observed was 7:1 with an average of 4:1; in general, stubby apatites dominate over acicular apatites. SEM observations show evidence of intensive apatite dissolution. All apatite grains can be classified as fluorapatite with 1.6-3.6 wt% of F [0.86-1.93 atoms per 2 (OH, F, Cl)] (Fig. 1) which is typical for all teschenites in the world (Henderson, Gibb 1987).

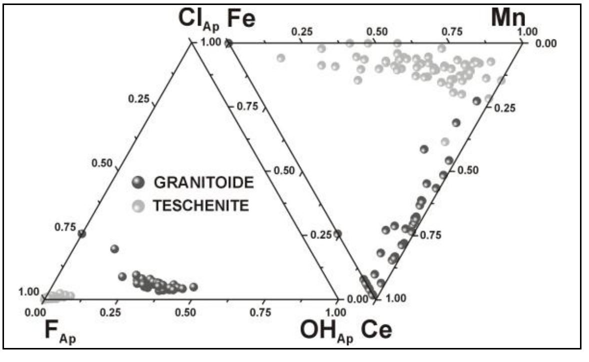

Fig. 1. Chemical composition of the investigated apatites

The second type of apatite crystals came from unusual cumulate granitic rock in the Starorobociański Peak (the Western Tatra Mountains) with a P_2O_5 content in the range 0.05-5.08 wt%. The apatites-(CaF) are up to 2 mm in size and are mostly represented by idiomorphic crystals showing internal zoning. The typical elongation is 6:1. The content of fluorine is in the range of 3.2-4.0 wt%. [1.6-2.00 atoms per 2 (OH, F, Cl)]. On the surfaces of the crystals, features typical of dissolution during syn/post- magmatic alternation can be observed. Both of the inverstigated apatite types differ in chemical composition (Fig. 1): the teschenite apatites are characterized by higher Sr and LREE contents while the granitic apatites show enrichment in Mn, Fe and Y. Our study indicates that compositional variations of apatite can be potentially used as indicators of magmatic and post-magmatic processes in plutonic rocks.

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Lanthanite-(La) as a new product of the reduction of bioavailable carbon in water: SEM and XRD study

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Phosphate ion (PO_4^{3-}) is the main nutrient causing pollution in most water reservoirs. Application, on a large scale, of La-reach bentonite is the best technique for reducing the bioavailable phosphorus in water. The product of phosphate-ion reduction is a mineral phase – rabdophane-(La) ($LaPO_4 \cdot H_2O$). The rabdophane-forming reaction takes place very fast and the end-product is stable in a wide range of pH and Eh conditions.

For this research, modified clay with a carbon nutrient-rich (CO_3^{2-}) water sample was used. After stirring of the mixed solution for 0.5 hour, it was kept for 1 day at room temperature after the residuum was heated at 50°C for 1 day. The effects of the reaction were investigated using a scanning electron microscope equipped with EDS (EDAX) detector and an X-ray diffractometer X'Pert Philips PW 3710 at the Faculty of Earth Sciences, University of Silesia.

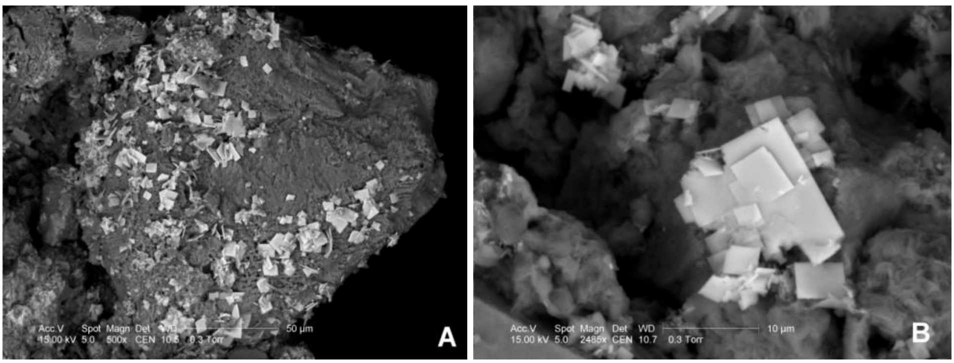

Fig. 1. Lanthanite-(La) on a bentonite grain (A) and a general view of its idiomorphic, twinned crystals (B).

The SEM study shows the presence of lanthanum-rich carbonate (Fig. 1A) that formed on clay aggregates. The platy, flattened carbonate crystals with rhombic shape are up to 20 µm in size (Fig. 1B). The X-ray data confirm the precipitation of lanthanite-(La) ($La_2[CO_3]_3 \cdot 8H_2O$) crystals.

As with the rabdophane-(La) forming process, the reaction resulting in lanthanite-(La) precipitation is effective and fast, and may have application in environmental science.

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Compositional variation in zircon from the aplite-pegmatite sill at Siedlimowice (Strzegom-Sobótka Massif, SW Poland) – an EPMA study

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The aplite-pegmatite sill at Siedlimowice is the largest pegmatitic occurrence in the eastern part of the Strzegom-Sobótka Variscan granitic massif. It intruded the two-mica granite host rock prior to the complete solidification of the granite as evidenced by partly-sharp and partly-diffused contacts with the sill. The up to 60 cm thick sill consists of aplite and weakly-zoned pegmatite. The pegmatite unit consists mostly of quartz, microcline microperthite, oligoclase, albite, biotite and muscovite with accessory almandine-spessartine, beryl, columbite, gahnite, apatite and zircon. Less common accessories include monazite, xenotime and uraninite. The pegmatite may be classified as a beryl-columbite subtype of the rare-element class.

Zircon usually occurs as up to 3 mm long euhedral crystals - combination of {101} and {110} forms. Some individuals display uneven margins with irregular embayments and sieve texture. EPMA analyses were carried out using a Cameca SX100 electron microprobe operating in the WDS mode at the Inter-Institute Analytical Complex for Minerals and Synthetic Substances, University of Warsaw. The following elements were analysed: P, Nb, Si, Ti, Zr, Hf, Th, U, Al, Sc, Yr, La, Ce, Pr, Nd, Gd, Dy, Ho, Er, Tm, Yb, Ca, Fe and Sm. Three compositional varieties are observed: 1: “normal” zircon, 2: Hf-poor and U-rich zircon, 3: Hf-rich zircon. Type 2 is observed only in larger crystals where it constitutes domains of probably relict nature. Type 3 occurs as veinlets within the Type 1 zircon.

The predominant **Type 1** “normal” zircon shows negligible substitution for Zr ($Zr \geq 0.949$ a.p.f.u.), $3.06 \leq HfO_2 \leq 4.38$ wt% and $0.13 \leq UO_2 \leq 2.91$ wt%. Th is mostly below detection limit. Zr/Hf ranges from 25-37. It contains numerous U-bearing inclusions and shows irregular patchy microtexture. **Type 2** is extremely U-rich with UO_2 up to 9.93 wt %. HfO_2 is low from 2.47-2.69 wt%. Y_2O_3 is elevated ranging from 1.06-1.52 wt%. Gd and Dy are present as traces while other REEs are below detection limit. U/Th is 63-112 and Zr/Hf 36-38. This type displays regular zoning and is relatively poor in inclusions. The analysis of the **Type 3** zircon shows that it is a hafnian zircon with 11.08 wt% HfO_2, 1.03 wt% of UO_2 and Zr/Hf = 9. The content of other elements is negligible (Zr+Hf = 0.991 and Si = 0.996 a.p.f.u.). Metamictization of the three zircon types is rather weak as suggested by totals close to 100% and low contents of elements commonly regarded as metamictization indicators such as Ca, Fe and Al.

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Hydrogarnets from picrite and teschenite sills in the Polish Western Carpathians

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Natural representatives of the isomorphous series $Ca_3Al_2(SiO_4)_3$ (grossular) - $Ca_3Al_2(OH)_{12}$ (katoite) are widespread natural phases described by earlier authors from many locations around the world. Members of this series with (SiO_4) substituted by $(OH,F)_4$ have formulae $Ca_3Al_2(SiO_4)_{3-x}(OH,F)_{4x}$, and classified as *hibschite* and *katoite*, represent the two solid solution fields with more or less than 50% Si in the tetrahedra, respectively (Passaglia, Rinaldi 1984).

In the Polish Western Carpathians, hydrogarnets were found in metasomatically altered veins of nepheline syenite in the teschenite sill in Puńców (an. 1-3, Table 1) and in the picrite sill in Międzyrzecze (an. 4-6, Table 1).

	1	2	3	4	5	6
SiO_2	32.46	32.41	32.47	29.12	23.30	24.85
TiO_2	3.17	1.27	0.07	0.89	4.41	0.02
ZrO_2	2.33	0.14	0.02	0.02	0.00	0.00
Al_2O_3	11.09	16.06	22.35	7.90	13.91	18.64
FeO	11.66	7.45	1.49	17.97	8.69	6.59
MnO	0.56	0.39	0.09	0.00	0.08	0.00
MgO	0.00	0.04	0.02	0.39	0.11	0.05
CaO	34.36	36.88	37.98	35.44	37.31	38.68
Na_2O	0.12	0.00	0.04	0.03	0.05	0.07
H_2O	1.92	3.31	3.44	5.35	10.11	9.64
F	1.39	2.17	3.68	0.11	0.28	1.14
O=F	-0.59	-0.91	-1.55	-0.05	-0.12	-0.48
Total	98.48	99.21	100.11	97.47	98.15	99.21
Katoite	8.48	13.92	13.95	23.33	41.75	38.61
FCa garnet	2.91	4.33	7.08	0.24	0.55	2.17
Kimzeyite	3.88			0.04	23.84	
Morimotoite	18.38	6.26		4.00		0.11
Spessartine	1.26	0.83	0.18		0.17	
Grossular	34.87	52.52	74.21	11.91	17.82	38.28
Andradite	28.72	20.65	3.60	58.32	14.81	19.65

Table 1. Chemical composition of hydrogarnets from the teschenite-picrite association.

In the Puńców sill, secondary F-bearing hydrogarnets form small, up to 0.4 mm in length irregular grains with anomalous birefringence among adularia, analcime, natrolite, and thomsonite. Garnets from the altered picrite sill mainly belong to the andradite-titanian andradite (melanite)-schorlomite series. Their crystals, *ca* 0.05-0.4 mm in diameter, form irregular or small rounded agglomerations among pectolite, natrolite, fluorapatite, calcite, titanite and chlorite. Individual grains have narrow rims (up to 10 µm) with hydrogarnet compositions (Table 1, an. 4-6). In general, all hydrogarnets from the teschenite-picrite association belong to the hibschite species, with x < 1.5.

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Petrography and spatial distribution of albitized granitoids in the Sudetes (Poland)

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Granitoids of the Sudetes in southern Poland often show an albitization expressed in typical reddish to pinkish colours and a specific paragenesis. In fact, the albitization consists of the replacement of the primary igneous feldspars by secondary neogenic albite, the chloritisation of the ferromagnesian minerals and the development of secondary minerals such as hematite, maghemite, and chlorite. The albitization is conventionally linked to deep processes (retrometamorphism, saussuritization, etc.). Nevertheless, recent studies show that albitization can also be linked to weathering processes related to the Triassic paleosurface (Ricordel et al. 2007; Parcerisa et al. 2010; Franke et al. 2010).

To understand the details of this petrology and to establish the spatial distribution of the albitized granitoids in the Polish Sudetes, three sites in the region were sample from NW to SE. The first site is the Szklarska Poręba quarry. The others are situated in the Laski valley and in the Chwaslislaw area, both in the Kłodzko district. The Szklarska Poręba quarry belongs to the Karkonosze Massif while the Laski and Chwaslislawsampling sites belong to the Kłodzko Złoty Stok Massif. These massifs are interpreted as Variscan intrusions by Mazur et al. (2007) and Bachliński & Bagiński (2007).

Several degrees of albitization can be distinguished: Strongly albitized facies are observed in the Laski granite. In the outcrop situated in the centre of the village, the granite is pervasively albitized. For the Szklarska Poręba granite outcrop and the Laski quarry granodiorite (situated at the north of the village of Laski), the albitization is restricted to fractures. Those fractures show decimetric gradients with reddish- and strongly-albitized facies at the walls and rather pinkish- and less-albitized facies further away from the fracture zones. The Chwalislaw granodiorite shows the weakest degree of albitization, with only pinkish spots within the presumably unaltered rock and a few thin albitized fractures.

In the albitized facies of the Laski village section, the primary igneous plagioclase crystals are entirely transformed into neogenic albite (often with the erasure of the twining pattern) and are also sericitized. Secondary chlorite develops along biotite cleavages and occurs as small euhedral crystals in fractures. Pigmentary hematite occurs in the neogenic albite, whereas in fractures, the hematite has a granular form. In the Laski quarry outcrop, the pinkish facies along the fractures shows replacement of the primary plagioclases (andesine-labradorite) by albite stained by hematite pigments. Biotite and hornblende are altered to chlorite.

In the Szklarska Poręba granite, the feldspars are solely K-feldspar and albite. Here, it is not easy to know whether the primary plagioclases are albitized or not, since the granite contains additional perthitic orthoclase which contains primary albite. The biotites in the Szklarska Poręba granite are chloritized. Hematite is sparse and occurs only along fractures. Maghemite is commonly more abundant than hematite in this granite than hematite, even in the darker facies away from fracture zones.

The Chwaslislaw granodiorite contains primary zoned plagioclases that are replaced by secondary albite in specific spots (about 200-500 μm in diameter), and in the pinkish walls of fractures. This albitization is associated with alteration of biotite and amphibole to chlorite as well as the additional development of maghemite.

Paleomagnetic results (Edel et al. 1997) indicate Triassic ages for the secondary hematite- and maghemite-containing facies related to the albitization processes (Franke et al. 2010). The development of the hematite and maghemite required oxidizing conditions, suggesting its link to weathering and therefore superficial environments. The Paleomagnetic datings indicate that the secondary minerals formed during albitization are related to the Triassic paleosurface. The intensity of the albitization decreases from the paleosurface downwards with depth. Therefore, the pervasively albitized granite of Laski village constitute a facies situated closer to the ancient land surface, whereas the fracture albitized facies of Szklarska Poręba and Laski quarry are rather linked to deeper horizons of the profile. The weakly albitized granodiorite of the Chwaslislaw section is related to the base of the paleoweathering profile.

Thus, mapping of albitized facies on a regional scale may allow characterization of the ancient landsurface (geomorphology) with a view to (1) estimating the geodynamic evolution and erosion rates since the Trias and (2) reconstructing the post-triassic structural history (fracturing, block movements, etc.) of the Variscan basement.

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Spessartite dyke in granite near Chwalisław

Field trip

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The record of differentiation and emplacement processes in lamprophyres (Kłodzko region, Sudetes, SW Poland)

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Introduction

The calc-alkaline lamprophyres of the Sudetes are a characteristic product of late- to post-orogenic mafic magmatism which occurred across the Variscan Orogen of Europe in Late Palaeozoic times. In the Sudetes, the lamprophyres, together with other associated mafic to felsic subvolcanic rocks, were emplaced as dyke swarms and scattered dykes in Carboniferous times (Awdankiewicz 2007). Although some lamprophyres in the Sudetes and elsewhere represent rocks that crystallized from rather primitive melts which underwent only weak modification after separation from mantle sources, many show various lines of evidence indicating shallow-level differentiation. These include features such as composite dykes, xenoliths and xenocrysts, heterogeneous phenocryst assemblages and/or variable zoning styles in phenocrysts, which reflect the contamination, fractionation and mixing/mingling of various melt batches during the rise, storage and emplacement. Deciphering the complex petrogenetic record contained in the petrography, mineralogy and geochemistry of lamprophyres is an intriguing scientific challenge.

This field trip is focused on selected occurrences of lamprophyres and related rocks in the Kłodzko region of the central Sudetes. The Gniewoszów Dyke Swarm and the Złoty Stok Dyke Swarm there show distinctive geological and petrological characteristics that reflect specific mantle magma sources and variable overprinting by shallow-level processes in separate magmatic systems (Awdankiewicz 2007). The four localities to be visited on the field trip will demonstrate selected rocks types belonging to both swarms, including minettes, spessartites, micromonzodiorites and microsyenites, and their country rocks. Problems related to the petrogenesis of these rocks will be discussed.

The geology of the Kłodzko region – an overview

The Kłodzko region is situated in the Central Sudetes. The late Proterozoic-Palaeozoic rock complexes of this area belong to the eastern part of the Variscan Belt of Europe (see Mazur et al. 2006 for more details). The major, high-grade metamorphic complexes of the Kłodzko region, i.e., the Orlica, Śnieżnik and Góry Sowie Massifs, are mainly composed of gneisses and schists with intercalations of marbles, amphibolites, granulites and eclogites. Others such as the Bardo and Kłodzko Units, and smaller crystalline massifs, comprise unmetamorphosed or low-grade (meta)sedimentary and (meta)igneous rocks of various provenance, including dismembered ophiolitic suite(s).

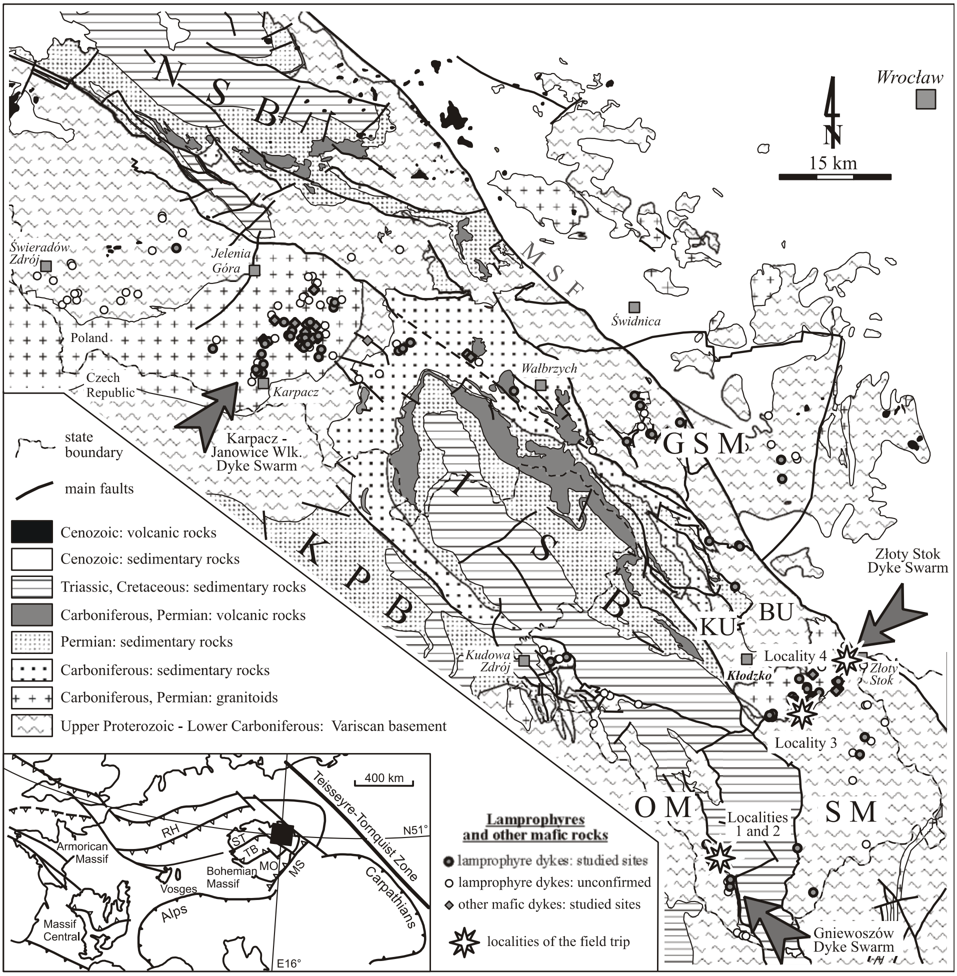

Fig. 1. Geological sketch map of the Lower Silesia region showing the distribution of lamprophyre dykes (modified from Awdankiewicz 2007). Geological structures mentioned in the text: BU – Bardo Unit; GSM – Góry Sowie Massif; ISB – Intra-Sudetic Basin; KPB – Karkonosze Piedmont Basin; KU – Kłodzko Unit; MSF – Marginal Sudetic Fault; NSB – North-Sudetic Basin; OM – Orlica Massif; SM – Śnieżnik Massif. See Figs 2, 5 and 7 for more detailed maps of the vicinities of the field trip localities. Inset: location of the main map (black square) within the Variscan Belt of Europe.

This geological mosaic records the late Proterozoic (Cadomian) orogeny, subsequent Cambro-Ordovician and Devonian rifting and, during the Variscan Orogeny, the multi-stage Late Devonian-Early Carboniferous collision and related metamorphism, deformation and uplift. In the Carboniferous, post-tectonic granitoid plutons were emplaced, the two largest of which are the Kudowa-Olesnice and Kłodzko-Złoty Stok Massifs (Bachliński 2007; Bachliński, Bagiński 2007). The Variscan complexes are overlain by the molasse deposits of the Intra-Sudetic Basin, a late Palaeozoic intermontane trough (Dziedzic, Teisseyre 1990, Mastalerz, Prouza 1995). The Permo-Carboniferous succession comprises mainly siliciclastic sedimentary rocks that originated in continental environments, as well as thick intercalations of acidic to basic volcanic rocks of calc-alkaline to mildly alkaline affinities (Awdankiewicz 1999 a, b; 2004). The Permian deposits are overlain by Lower Triassic and Upper Cretaceous sedimentary rocks, mainly sandstones of continental and marine origin that form the epi-Variscan platform cover. Amongst the most recent rock formations of the Kłodzko region are small occurrences of Pliocene basaltoids near Lądek Zdrój (Birkenmajer et al. 2002). These, considered to be the youngest volcanic rocks in Lower Silesia, are related to the Cenozoic rifting in Central Europe.

The Gniewoszów and Złoty Stok Dyke Swarms

The Gniewoszów Dyke Swarm (GDS) is situated the eastern part of the Orlica-Śnieżnik Massif. The swarm comprises several dykes of minette and richterite minette concentrated in a NNW-aligned area 7 x 4 km in size. The dykes, ranging up to 10 m in thickness and probably 200 m in length, cut mica schists, intercalated marbles and amphibolites. Ar-Ar dating of dark mica and amphibole from two minette samples indicate dyke emplacement at ~ 328-329 Ma (Awdankiewicz, Timmerman, unpublished).

The minettes consist mainly of phlogopite phenocrysts in a groundmass of K-feldspar. The richterite minettes contain, in addition, abundant groundmass richterite (see description of locality 2 for more details). In terms of chemical composition (Awdankiewicz 2007), these rocks are intermediate to acidic (SiO_2 from 54% to 67%), mostly ultrapotassic (K_2O/Na_2O of 4-20 at MgO of 8-3%), Mg-rich (magnesium numbers from 79 to 30; Mg# = 100xMgO/(MgO+FeO*), in mol. proportions with total Fe as FeO), rich in Cr (500-200 ppm) and Ni (200-100 ppm). The normalized trace element patterns are characterized by relatively flat trends for the high field strength elements at a high level (~ 100x mantle values), by strong enrichment in Th and U, limited Nb and Ta depletion and strong depletion in Sr and Ti. The richterite minettes tend to show lower SiO_2 and higher Mg#, Cr and Ni, whereas the minettes are more evolved and enriched in silica and several incompatible trace elements such as Zr, Nb and Ce. A relatively small variation in incompatible trace element ratios is observed; e.g. Zr increases from 500 to 1500 ppm and Nb from 30 to 90 at Zr/Nb of ca 15-20. The richterite minettes and minettes also show similar high values of $^{87}Sr/^{86}Sr_{300Ma}$ (~ 0.7123) and low values of εNd_{300Ma} (ca -8).

The petrological characteristics of the minettes in the GDS are mostly related to their mantle sources and only partly modified by shallow-level processes (discussion in Awdankiewicz, 2007; see also explanations for locality 2). The richterite minettes derived from a phlogopite- or amphibole-bearing mantle source at low degrees of partial melting and relatively low pressures, possibly spanning the transition between garnet- and spinel peridotites. The magma source was contaminated by subducted crustal rocks. The minettes of the GDS are most probably related to the richterite minettes by fractional crystallization of phlogopite and apatite.

The Złoty Stok Dyke Swarm (ZSDS) comprises dykes that crop out in the Kłodzko-Złoty Stok granite, mainly in the southern and eastern parts of the pluton, and also locally within the schists and gneisses of the Śnieżnik Massif forming the southern cover of the pluton. The dykes, concentrated in a NE-aligned area 15 x 6 km in size, show variable strikes with steep dips. Most dykes are only tens of centimetres thick, some are up to a few hundred metres long. The lamprophyres are vogesites and spessartites and the associated mafic to felsic rocks are fine-grained equivalents of various dioritic, syenitic and granitic rocks (Wierzchołowski 1977, Awdankiewicz 2007). A SHRIMP zircon study indicates intrusion of spessartites at ~ 333 Ma (Mikulski, Williams, this volume).

The ZSDS lamprophyres are mesocratic rocks characterized by the presence of amphibole phenocrysts (tschermakite, magnesiohastingsite, pargasite, edenite, magnesiohornblende) accompanied by clinopyroxene (augite to diopside) and biotite in a groundmass dominated by alkali feldspars in the vogesites or by plagioclase in the spessartites. The amphibole phenocrysts show variable zoning patterns. Quartz and plagioclase xenocrysts occur in the vogesites and, more rarely, in the spessartites. The other mafic to felsic rocks are generally distinguished by a lower colour index as well as by the presence of feldspar phenocrysts. Some microsyenites contain abundant Na-Ca amphiboles (richterite, winchyte).

The ZSDS rocks are typically intermediate to acidic (SiO_2 from 57-63%) with subalkaline to mildly alkaline affinities and relatively rich in Mg (Mg# from 70-50). The vogesites show the most primitive characteristics: one specimen is a basic rock with 51% SiO_2 and the highest Cr and Ni contents of 530 ppm and 240 ppm, respectively. The normalized trace element patterns are characterized by enrichment in the large-ion lithophile elements and of the light rare earth elements over the high field strength elements, resulting in significant negative anomalies at Nb, Ta and Ti. In the vogesites, spessartites and micromonzodiorites, there is a well-defined linear variation of Zr and Nb (Zr from 100-300 ppm, Nb from 5-15 ppm, Zr/Nb usually about 20). The Sr and Nd isotopic characteristics of the rocks are very similar, with $^{87}Sr/^{86}Sr_{300Ma}$ of ca 0.7082 and εNd_{300Ma} of ca -4.3. However, the microsyenites from Rogówek (Locality 3), and also the spessartites from Chwalisław (Locality 4) show some distinct geochemical characteristics, such as the contents and ratios of Zr and Nb.

Compared to the GDS, the ZSDS shows a much more pronounced petrographic- and geochemical diversity reflecting different mantle sources and the evolution of the melts in a complex magmatic system (Awdankiewicz 2007). The parental magmas originated from a heterogeneous mantle source which was contaminated by subducted crustal rocks and which also contained domains metasomatized by subduction-related fluids. The petrographic evidence, e.g., the presence of xenocrysts and variable zoning styles in amphibole phenocrysts, suggests that open-system processes such as magma mixing were involved. In contrast, the small variations in the Sr and Nd isotopic ratios and in the incompatible trace-element ratios (e.g., Zr/Nb) suggest closed-system differentiation processes. Perhaps, magma mixing processes affected only the more primitive compositions at the early differentiation stages and the more evolved melts originated mainly due to fractional crystallization. However, the fractionation paths were strongly dependent on the emplacement and degassing history of parental melts within the magmatic system. The water-rich parental vogesite magmas emplaced at greater depths suffered only limited volatile loss, crystallized amphibole-dominant mineral assemblages, and the fractionated daughter melts crystallized as spessartites. On the other hand, similar parental magmas emplaced at shallower levels could have lost more volatiles and crystallized plagioclase-dominant assemblages with the formation of monzodioritic daughter melts (Awdankiewicz 2007).

LOCALITY 1

Metabasites from the Stronie Formation near Gniewoszów, southern part of the Bystrzyckie Mts.

Leaders: Sławomir ILNICKI, Jacek SZCZEPAŃSKI

Location: Gniewoszów – rock crags near Szczerba Castle (N50 11 39.1 E16 37 15.7)

The Bystrzyckie Mts forming the western part of the Orlica-Śnieżnik Massif (OSM), comprise a large orthogneiss body (the Bystrzyckie orthogneiss, ca 500 Ma; Kröner et al. 2001) mantled by the Stronie Formation. The latter, originally a metasedimentary cover to the orthogneiss protolith, is a relatively thick (4000-5000 m) sequence of mica schists, paragneisses, marbles and mafic and felsic metavolcanics. The sequence is believed to be of Late Proterozoic or Early Paleozoic age (Gunia & Wierzchołowski 1979). More information on the geology of the Bystrzckie Mts is given in Szczepański (this volume). The metamorphic rocks of the Stronie Formation are locally cut by lamprophyre dykes of Carboniferous age that belong to the Gniewoszów Dyke Swarm (Locality 2).

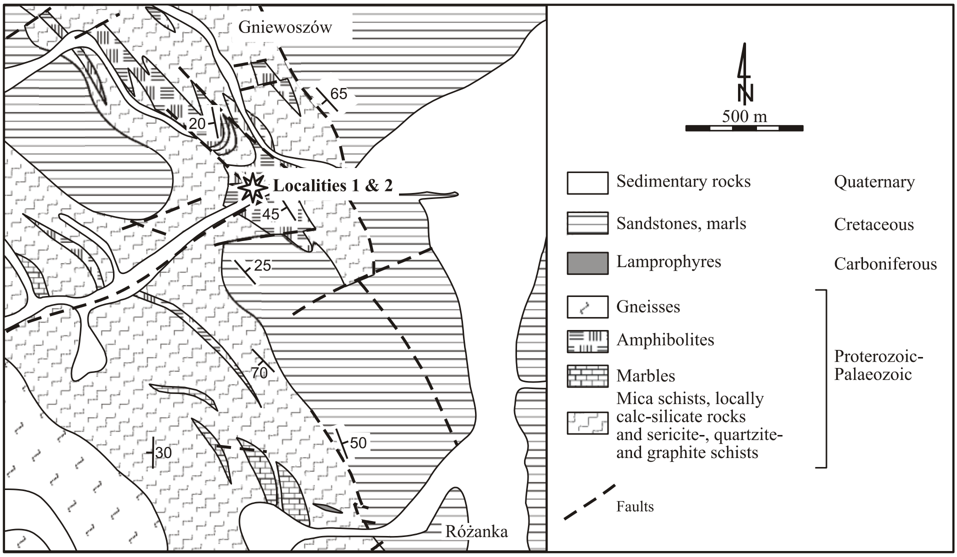

Fig. 2. Geological sketch map of the Gniewoszów vicinity showing Localities 1 and 2 (modified from Kozdrój 1994 and Walczak-Augustyniak, Wroński 1982). The general location of the area is indicated in Fig. 1.

The mafic metavolcanics near Gniewoszów (Fig. 2) occur as relatively large, up to 50-70 m thick, bodies. Near Szczerba Castle particularly, they display structures interpreted as strongly deformed pillow-lavas (Fig. 3 A-C). The pillows range from several tens of centimetres (Fig. 3 B, C) to 2-3 m in diameter (Fig. 3 A).

The metabasites are fine-grained, in some cases porphyroblastic, rocks with moderately- to well-developed foliation and mineral lineation. They are composed mainly of amphibole and plagioclase, subordinate chlorite, epidote, ilmenite and accessory quartz, biotite, apatite, titanite, rutile, zircon and potassium feldspar.

The metabasites are generally classified as basalts and, on several classification diagrams, show a mostly tholeiitic affinity. The chondrite-normalized patterns display mocerateenrichment in LREE (average chondrite-normalised La/Yb = 1.9 ± 0.7), fairly flat HREE patterns and slightly elevated chondrite-normalised Tb/Yb (average 1.3 ± 0.1).

MORB-normalized diagrams of trace-element contents show variable enrichment in LILE or LREE (abundances up to 6 x MORB) and a systematic decrease in contents from La towards the least incompatible elements; negative Nb(-Ta) anomalies are variably pronounced. The source of the metabasite protolith was presumably more enriched than that of N-MORBs – as shown by the REE and multi-element profiles. Moreover, the ranges of, and variations in, their incompatible trace element ratios (e.g., Ta/Yb, Zr/Nb, La/Yb) may reflect a slightly-enriched (fertile) asthenospheric source which was subjected to moderate and different degrees of partial melting (ca 10-15%). Alternatively, a heterogeneous source in which depleted- and enriched components were melting and mixing may be proposed. It is also plausible that both factors, i.e., variable degrees of partial melting and source heterogeneity, may have influenced the magma compositions. Melts were probably generated at shallow levels (60-55 km) within the spinel peridotite facies.

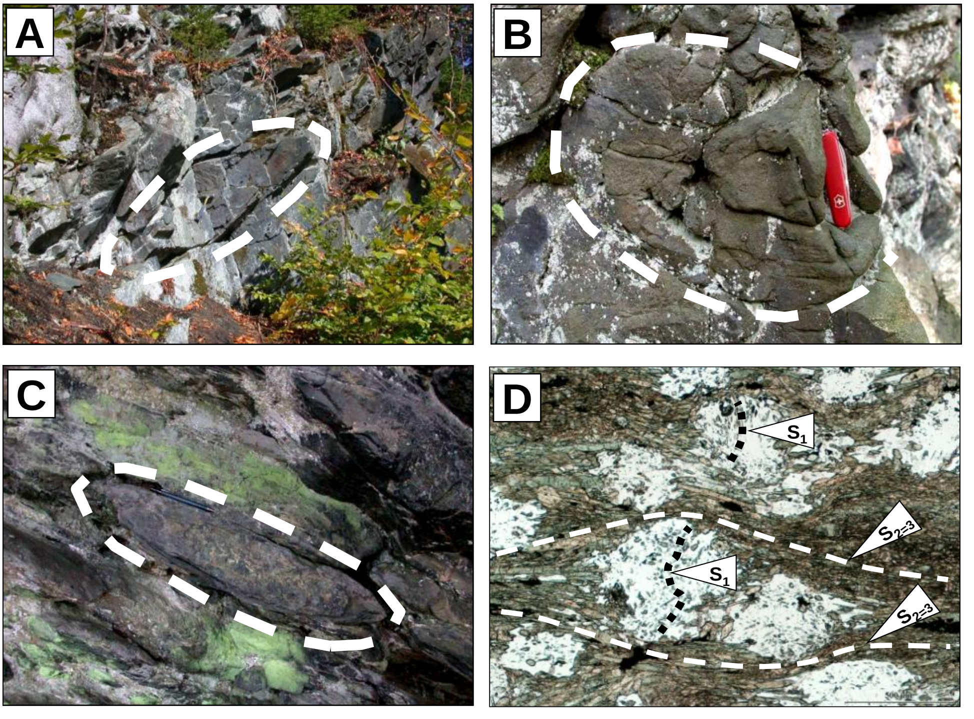

Fig. 3. A-C. Heterogeneously deformed pillow-lava structures (marked with dashed line) in metabasites in the Gniewoszów vicinity. D. Microphotograph of metabasite with marked complex foliation planes (S_{2+3}) anastomosing around plagioclase porphyroblast. Inclusion trails in the porphyroblasts are relics of an earlier foliation (S_1).

The geochemical features of the metabasites reflect not only asthenospheric heterogeneity but perhaps also the introduction of a subduction-derived component into the parental magmas. On discrimination diagrams, the rocks reveal affinities to either E-MORB-to-N-MORB or back-arc basin basalts (BAB). Furthermore, on the Nb/Yb-Th/Yb plot, the majority of the rocks tend to plot above the mantle array, suggesting enrichment by a subduction-related component. On the other hand, this feature and several other geochemical signatures, could also have originated through crustal contamination of variable intensity, thus negating the inferred influence of a subduction zone and any BAB affinity. Thus, these metavolcanics would be MOR-type basalts that originated during extension beneath strongly-thinned and attenuated lithosphere (presumably during the Cambro-Ordovician break-up of the northern periphery of Gondwana) or alternatively in a back-arc setting related to an unspecified subduction event.

Three separate Variscan deformation events affected the metabasites. The first (D1) produced an S1 foliation defined by thin, folded amphibole laminae that are mainly preserved in microlithons between younger foliations, and as inclusion trails in plagioclase porphyroblasts (Fig. 3 D). During D2, the S1 foliation was folded into F2 isoclinal folds with an axial-planar cleavage (S2). In places, S2 planes are developed as a crenulation cleavage. The D3 deformation event was associated with reactivation of the older S2 structure producing a complex S2+3 foliation (Fig. 3 D).

Textural and compositional relationships enable the identification of mineral assemblages defining metamorphic events. An earlier event (M1) is characterised by the assemblage actinolite + albite ± chlorite ± epidote which defines the S1 foliation plane. A later event (M2) produced the assemblage tschermakite/pargasite (Mg-hornblende) + oligoclase/andesine (bytownite) ± chlorite ± epidote + ilmenite which defines the complex S2+3 plane. In the western part of the Bystrzyckie Mts, the peak assemblage is Fe-tschermakite + andesine/bytownite. A final retrogressive assemblage (M3?) comprises albite + chlorite + epidote/allanite + K-feldspar ± calcite ± sericite. The metabasites document a westward transition from greenschist- to amphibolite-epidote or amphibolite facies conditions, with retrograde metamorphism under greenschist facies conditions. The peak metamorphism corresponds to the biotite, garnet (field stop 1a at Szczerba Castle) and staurolite-kyanite zones. The P-T conditions for M1 were 450-500°C and 1.8-4.2 kbar. The conditions of peak metamorphism (M2) differ between samples and display a distinct spatial zonation: 540°C, 3.5 kbar in the north-east, 565°C, 6.4 kbar around Gniewoszów and 650°C, 7.3 kbar in the west.

The P-T estimates for the metabasites in the southern part of the Bystrzyckie Mts provide evidence for two distinct metamorphic events related to different deformation episodes. The earliest metamorphism (M1) is related to the D1 deformation recognized regionally. Prograde evolution and peak metamorphic conditions (M2) in these metabasites were attained during the D2 and the D3 events. The M2 metamorphic episode shows a westward increase in temperatures towards the contact zone between the Nové Město and the Orlica-Śnieżnik units, typical of Barrovian-type metamorphism. The D2 event corresponds to emplacement of the Bystrzyckie Mts crystalline nappes and folding resulting from the early juxtaposition of the Nové Město and Orlica-Śnieżnik units (Mazur et al. 2005). The D3 event is possibly associated with dextral strike-slip shearing along the contact of the Teplá-Barrandian and Moldanubian terranes at 340 Ma.

LOCALITY 2

Minettes of the Gniewoszów Dyke Swarm

Leaders: Marek AWDANKIEWICZ, Honorata AWDANKIEWICZ

Location: Gniewoszów – rock crags SW of Szczerba Castle (N50 11 35.6 E16 37 10.3)

Locality 2 is a group of crags situated ~ 140 m SSW of Szczerba Castle. The crags extend for several tens of meters and reach up to 20-30 m above the valley floor. The lower parts of the crags are amphibolites (compare Locality 1) which form the country rocks of a richterite minette dyke exposed in the highest part.

The dyke, striking NNW, is ~ 120-150 m long and up 10 m thick. At Locality 2, the minette shows well-developed platy joints (Fig. 4 A) and a magmatic foliation (Fig. 4 C) defined by the alignment of dark mica plates. These structures, dipping steeply to the N-NE, probably parallel the poorly-exposed margins of the dyke. The minettes are usually medium-grained to porphyritic rocks. Almost aphanitic rock in loose blocks most likely comes from the chilled margins of the dyke. In places, the minettes host leucocratic, medium- to coarse-grained (pegmatitic) veins (Fig. 4 B). These veins, up to ~ 1 cm wide and 1 m long, are subparallel to the flow foliation of the minettes, with local folding and disruption. Rarely, the minettes contain fine-grained melanocratic enclaves, 2-3 cm long (Fig. 4 B).

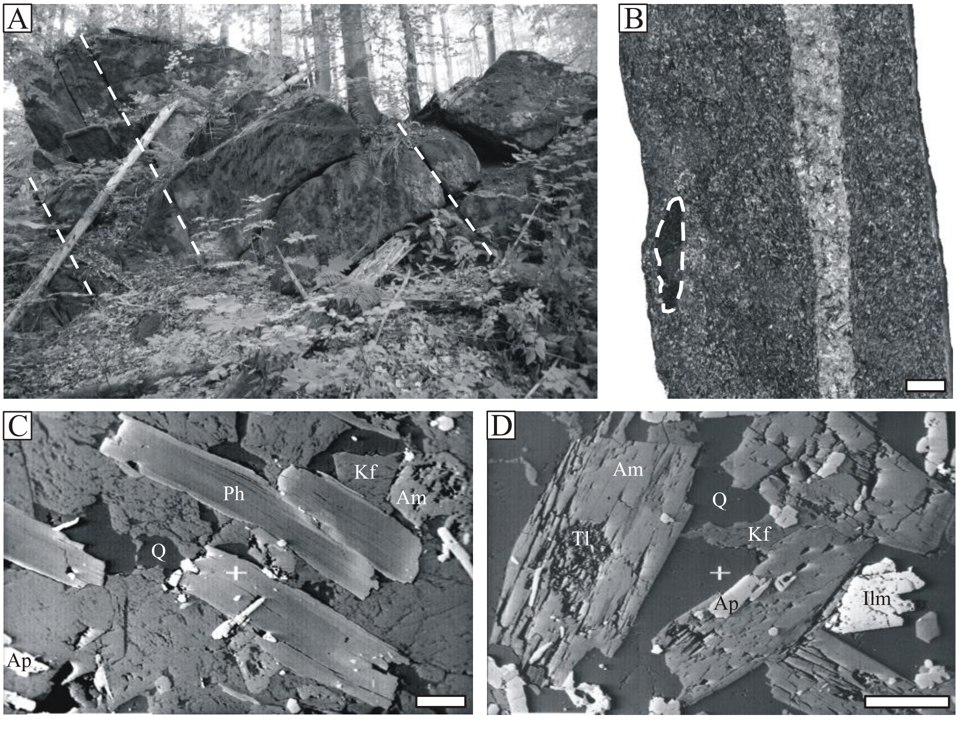

Fig. 4. A – richterite minette dyke at Locality 2. Broken lines show the orientation of platy joints and flow foliation. B – polished slab of the richterite minette at Locality 2 with a leucocratic vein and a melanocratic enclave (outlined). Scale – 1 cm. C and D – back-scattered electron images of the richterite minette showing the main minerals and textures. Details in text. Scale bar – 200 µm. Am – amphibole (richterite, winchyte); Ap – apatite; Ilm – ilmenite; Kf – K-feldspar (dark patches in Kf – albite); Ph – phlogopite-biotite; Q – quartz; Tl – talc.

The richterite minette at this locality is a mesocratic rock composed mainly of dark mica, K-feldspar, amphibole and small amounts of ilmenite, titanite, apatite, albite and quartz (Fig. 4 C, D). Rare aggregates of talc and clay minerals are possibly pseudomorphs after phenocrysts of olivine or pyroxene. The textures of the minettes range from porphyritic to poikilitic with a typical thin section containing domains of both. In the porphyritic domains, aligned dark-mica phenocrysts up to 3-4 mm long are set in a fine-grained to microcrystalline groundmass of euhedral to subhedral mica, amphibole, K-feldspar and the accessory minerals. Interstitial anhedral quartz and albite are also present. The poikilitic domains are distinguished by K-feldspar poikilocrystals up to 5 mm long enclosing smaller crystals of the other minerals.

The dark mica forms euhedral platy crystals of pale- to rusty-brown colour. The inner, pale-coloured parts of the plates are phlogopite in composition, whereas the strongly coloured margins are zoned to biotite. Prismatic crystals of amphiboles are pleochroic from yellowish-green to pale-brown. Most amphiboles are richterite, less commonly winchyte and, locally, there are overgrowths of actinolite. The cores of some amphiboles enclose oval pseudomorphs composed of small phlogopite and Fe-bearing talc flakes. The K-feldspars, Or90-95 in composition, with up to ca 1% BaO, contain haematite-stained brownish patches as well as albite microperthites in the form of veins, patches and lamellae, the latter only 1-2 μm wide.

The leucocratic veins and the melanocratic enclaves noted above show modal compositions similar to those of the minettes. However, the veins are depleted, and the enclaves enriched, in the coloured minerals. A characteristic feature of the veins is the presence of interstitial graphic intergrowths of K-feldspar and quartz. The composition of the dark mica in the melanocratic enclaves is similar to that of the mica phenocrysts in the host minette.

The locality visited is the most interesting in the Gniewoszów Dyke Swarm because of the good exposure and the very limited post-magmatic alteration of the minette. The petrographic features and whole-rock chemistry suggest that the richterite minette corresponds to a primitive melt derived from contaminated- and hydrated peridotite or pyroxenite (discussion in Awdankiewicz 2007). The geochemical evidence includes the silicic, ultrapotassic composition (SiO_2 = 57%, K_2O/Na_2O = 4.6) and the crustal isotopic signatures (e.g., εNd_{300Ma} = -8.3) at high MgO (8.3%), Cr (440 ppm) and Ni (104 ppm) contents. The minette shows also a significant negative Eu anomaly (Eu*/Eu = 0.54). Negative Eu anomalies, common in evolved igneous rocks, are usually explained by fractional crystallization of plagioclase (e.g. Wilson 1989). However, the minette discussed does not contain plagioclase and K-feldspar occurs in the groundmass only. Therefore Awdankiewicz (2007) proposed that in these minettes the Eu anomaly may be inherited from the mantle source of magma, contaminated by crustal rocks with negative Eu anomaly.

The specific bulk composition of the minette is reflected in the modal mineralogy which includes relatively rare Na-Ca amphiboles. The emplacement, cooling and crystallization of the richterite minette magma in the dyke were associated with the development of flow foliation and the segregation of late-stage, residual melts such as the leucocratic veins. The melanocratic mica-rich enclaves could have formed earlier, during the rise of the minette magmas. Other emplacement- and cooling-related processes included magma chilling at dyke margins, exsolution of microperthite in alkali feldspars and the replacement of olivine (or pyroxene?) by post-magmatic talc and clay minerals.

LOCALITY 3

Microsyenite dykes in the Kłodzko-Złoty Stok granitoids

Leaders: Marek AWDANKIEWICZ, Honorata AWDANKIEWICZ

Location: Rogówek – old quarry (N50 22 25.8 E16 44 55.1)

Locality 3 is an old quarry situated to the south of the village of Rogówek, near the road from Ołdrzychowice Kłodzkie to Skrzynka. The partly overgrown quarry is ~ 40 m in diameter and ~ 12 m high. The quarry lies near the southern margin of the Kłodzko-Złoty Stok pluton (Fig. 5). The rocks exposed are cordierite-plagioclase-microcline gneisses, granodiorites and microsyenites (Cwojdziński 1979 a, b).

The gneisses that occur in the eastern part of the quarry are part of a large raft, several metres wide and tens (to hundreds?) of metres long, enclosed in granites (cf. Cwojdziński 1979 a, b; Fig. 1 in Cwojdziński 1981). The raft is subvertical and strikes NW. Foliation within the gneisses is subparallel to the elongation of the raft. Similar, smaller rafts/xenoliths and interdigitations of gneisses and granites can also be observed in other parts of the quarry. The microsyenites form a system of short, irregular dykes, tens of centimetres to metres wide, set within granites or near the contacts between granites and gneisses (Fig. 6 A). Smaller well defined veins, centimetres thick and decimetres to metres long, penetrate into adjacent rocks from the main microsyenite bodies (Fig. 6 B). The boundaries of the microsyenites with the host rocks are sharp. In places, the microsyenites contain cm-sized xenoliths of granites and/or gneisses.

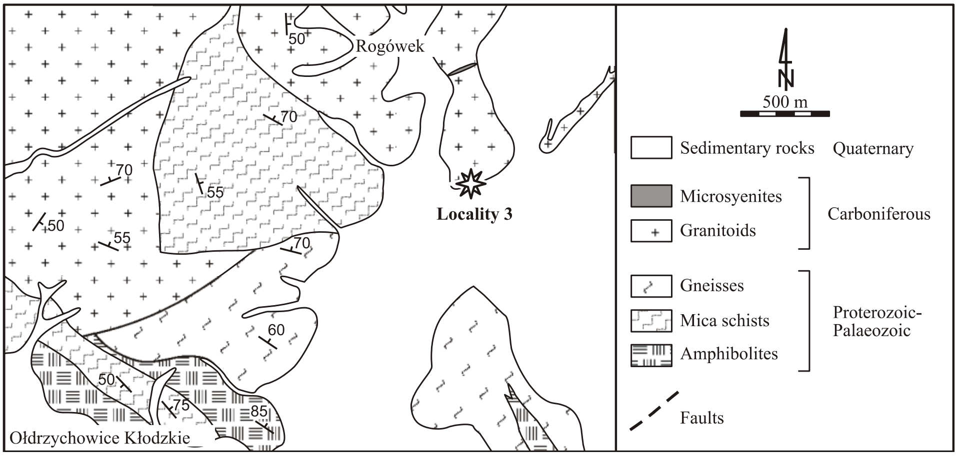

Fig. 5. Geological sketch map of the vicinity of the Rogówek quarry (Locality 3; modified from Cwojdziński 1979a, b). The general location of the area is indicated in Fig. 1.

The strongly predominant lithology in the dykes is an aphyric, mesocratic microsyenite (type 1). This rock locally shows an indistinct banding. The bands, mm to cm thick, are classified as aphyric, leucocratic microsyenite (type 2) and feldspar-phyric, leucocratic microsyenite (type 3). Within this petrographic spectrum, there are gradations with types (1) and (3) representing the most characteristic 'end-members'.

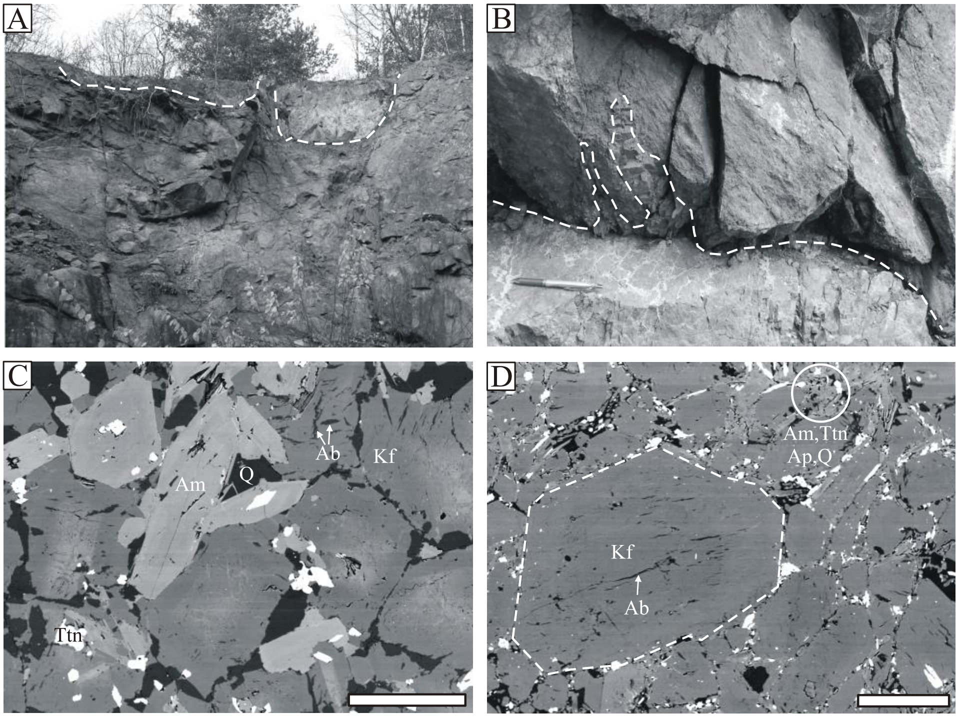

Fig. 6. A – short dykes of microsyenites (outlined) in granites and gneisses at Rogówek. B – thin vein of microsyenite projecting from a larger microsyenite mass into adjacent granite. C and D – back-scattered electron images of the aphyric, mesocratic microsyenite (C) and the feldspar-phyric, leucocratic microsyenite (D). Brighter K-feldspar cores in (C) are enriched in BaO. K-feldspar microphenocryst is outlined in (D). Details in text. Scale – 200 μm. Ab – albite; Am – amphibole (richterite, winchyte, potassic richterite); Ap – apatite; Kf – K-feldspar; Q – quartz.

The aphyric mesocratic microsyenite (Fig. 6 C) is very fine grained, phaneritic to almost aphanitic. It is an inequigranular, euhedral- to subhedral-granular and massive rock that consists predominantly of platy and prismatic K-feldspars and amphiboles. Larger, 0.3-0.4 mm long, crystals of these two minerals, together with minor chloritized dark mica, comprise the framework, whereas the less abundant and smaller diopside, titanite and apatite crystals occur as inclusions in amphiboles, K-feldspar and in anhedral, interstitial quartz. The amphiboles in the aphyric microsyenite are pleochroic in brownish to bluish-green. It is usually richterite and winchyte with the latter tending to occur at the margins of larger crystals and as smaller elongate crystals in the interstices. In places, there are overgrowths and intergrowths of actinolite as well as radiating aggregates of actinolitic amphibole. The K-feldspar is microcline (Or83-98) with well-developed hatching. Many crystals show 'rusty' cores stained by Fe oxide / hydroxide and enriched in BaO (up to 2.6 wt%, corresponding to ~5% of the celsian molecule). In many microclines, there are also micropehrtites of almost pure albite (Ab98-99) in the form of lamellae and small patches.

The feldspar-phyric leucocratic microsyenites (Fig. 6 D) are mainly distinguished by microporphyritic- and trachytic texture. Microphenocrysts and groundmass crystals of K-feldspar, the predominant mineral, make up the framework of the rock. The interstices are filled with anhedral quartz which contains numerous small crystals of amphibole, titanite, apatite and zircon. Many K-feldspar crystals contain inclusions of acicular amphibole aligned in thin bands along the margins. This amphibole is potassic richterite, less commonly, richterite, winchyte or potassic Mg-arfvedsonite. The K-feldspar is microcline (Or88-95) typically with albite microperthite. The BaO content of the K-feldspars is typically below 0.9 wt% (< 1.6% of the celsian molecule).

The microsyenites from this locality are acidic rocks rich in potassium (SiO_2 ca 62-67%, K_2O ca 10%) with moderate to low contents of MgO, Cr and Ni (ca 2-4%, 100-200 ppm and 50 ppm, respectively). They are strongly enriched in some incompatible trace elements, e.g., Nb (up to 110 ppm) and Zr (from 600-1300 ppm, and up to 2000 ppm in another dyke north of the quarry). These geochemical characteristics make them different from the vogesite and spessartite dykes typical of the ZSDS, but there are some similarities to the richterite minettes of the GDS (Awdankiewicz 2007).

The locality is one of the most intensely studied occurrences of hypabyssal rocks in the Kłodzko-Złoty Stok Massif. Cwojdziński (1981) classified the hypabyssal rocks as semilamprophyres. Noting their peculiar forms, and petrographic and geochemical differences between them and lamprophyres cutting the Kłodzko-Złoty Stok pluton, Cwojdzinski (1981) suggested that the rocks represent a pre-granitic dyke emplaced into gneisses and later disrupted and recrystallized during the intrusion of the Kłodzko-Złoty Stok granites. Wierzchołowski (2003) classified the dyke rocks as vogesites, microsyenites and alkali microsyenites, discussed their geochemical- and mineralogical characteristics and concluded that the vogesites are genetically unrelated to the host granitoids but formed due to contamination of a syenitic magma by “material rich in metamorphic amphiboles”.

The observations presented here enable the above conclusions and preliminary reinterpretations to be re-evaluated. The petrographic features of the dyke rocks from Rogówek favour their classification as microsyenites rather than vogesites, mainly because the presence of feldspar-phyric rocks instead of amphibole-phyric rocks. The spatial relationships between the granititic rocks and the microsyenites, and the veins cutting granites in particular, show that the microsyenites are, in fact, post-granitic, not pre-granitic. The specific form of the larger microsyenite bodies may be due to their emplacement near the contact between granite and country rocks when the pluton was yet not fully consolidated. Shearing along the pluton margin could have disrupted the intruding microsyenite magma into several pockets/irregular dykes. The petrographic variation and flow banding in the microsyenites indicate that the intruding microsyenite magma was heterogeneous in terms of crystallinity and/or chemical composition, or that some in-situ differentiation and segregation occurred. The geochemical characteristics of the microsyenites may suggest some genetic links to magmas resembling the richterite minettes of the Gniewoszów Dyke Swarm; this is a possibility requiring further evaluation. The actinolitic amphiboles in the microsyenites are, as in other hypabyssal rocks of the Sudetes (e.g. Awdankiewicz 2007), of post-magmatic origin rather than due to contamination as suggested by Wierzchołowski (2003).

LOCALITY 4

Spessartites of the Złoty Stok Dyke Swarm
Leaders: Marek AWDANKIEWICZ, Honorata AWDANKIEWICZ
Location: old quarry N of Chwalisław (N50 26 07.7 E16 49 47.5)

This locality is an old granitic quarry situated ca 1km from the SE margin of the Kłodzko-Złoty Stok pluton (Fig. 7) and west of the road between the villages of Mąkolno and Chwalisław. The quarry is ~ 40 m wide and up to 25 m high in the central part.

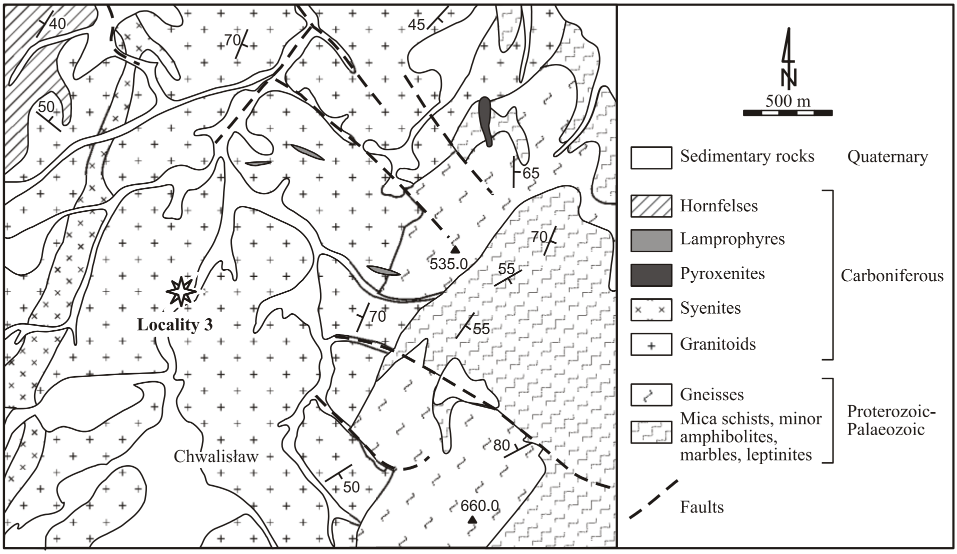

Fig. 7. Geological sketch map of the Chwalisław vicinity showing Locality 4 (modified from Cwojdziński 1976). The general location of the area is indicated in Fig. 1.

The biotite-hornblende granodiorites in the quarry and around are cut by several dykes of spessartite and micromonzodiorite. In the quarry, there are two zones that are injected with dykes. The SW zone is 5-10 m wide and comprises several dykes 50-20 cm thick, and thinner dykes, forming a network of cross-cutting veins. Most are spessartites. The dykes dip steeply to the north-east and east. The NE zone is ~ 5 m thick and comprises two well defined dykes, ~ 50 cm and 110 cm thick, dipping steeply to the east. There are several thinner offshoots around and between the two main dykes, locally forming a network. The dykes in the NE zone are micromonzodiorites. In both zones, contacts of dykes with the host granites are sharp and wavy, with irregularities cm to dm in amplitude (Fig. 8 A, B). The dykes are massive with irregular cracks; only mm-wide zones at the contact with granites show indistinct foliation. Other features, described also by Wierzchołowski (1977), include local zones of brecciated granite cemented with dyke rock, cm-sized xenoliths of granite in dyke rock, mm-wide chilled zones at the margins of dykes, and mm-scale zones of cataclased granite at dyke contacts.

The spessartites and micromonzodiorites from Chwalisław are microporphyrtitic (phenocrysts typically <1 mm long) with a microcrystalline, trachytic-textured groundmass. Although the dykes appear relatively monotonous, they show a significant diversity of textures and mineral assemblages (Fig. 8 C, D, E). The colour index ranges from 45-25. Phenocryst assemblages vary from amphibole-dominated to biotite-dominated, with smaller but variable amounts of diopside, plagioclase and chlorite pseudomorphs after a ferromagnesian mineral. Some rounded quartz crystals and sieve-textured plagioclases are xenocrysts. Mesocratic rocks with abundant amphibole phenocrysts are classified as spessartites. Rocks with lower colour index and with plagioclase phenocrysts are transitional spessartites/micromonzodiorites and micromonzodiorites. There are also variations in mineral compositions and zoning patterns, especially in amphibole and plagioclase.

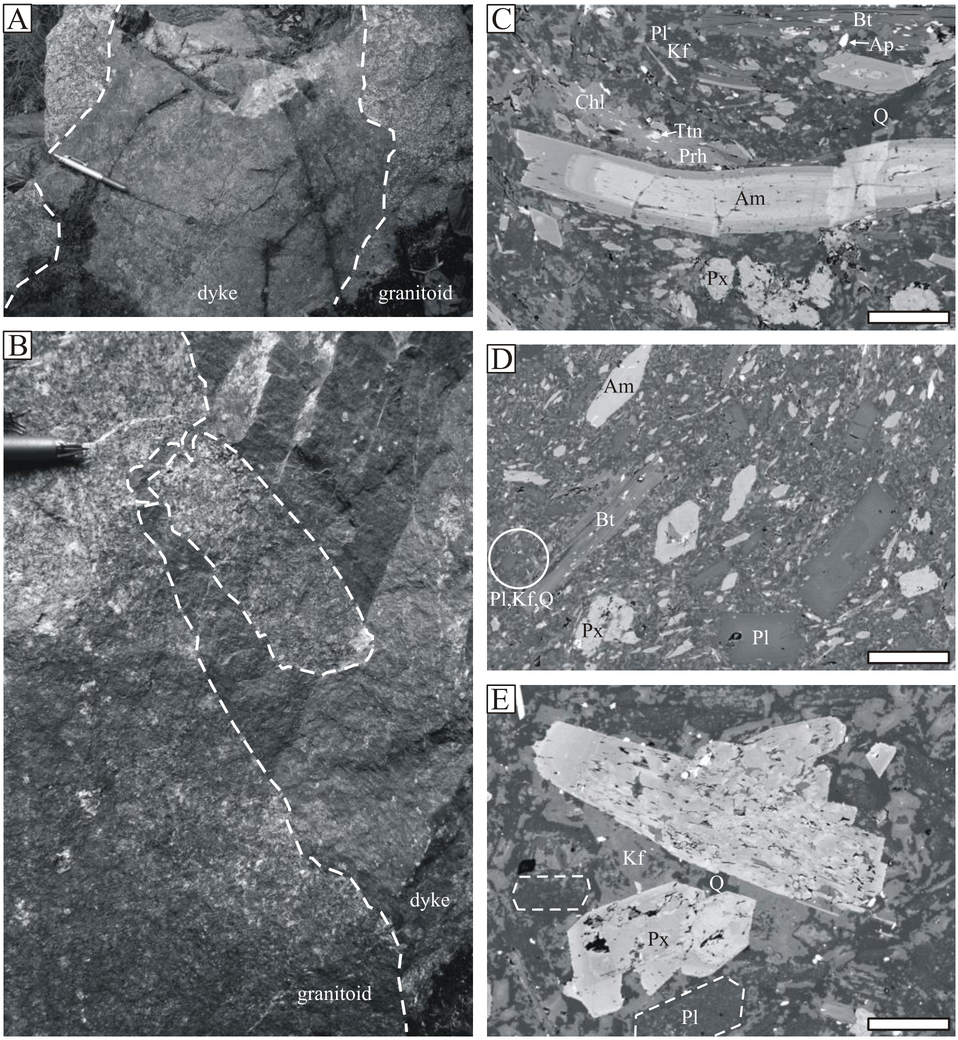

Fig. 8. A, B – spessartite and micromonzodiorite dykes in granites at Chwalisław. The photographs show the uneven, wavy margins of the dykes and dyke-granite interdigitation. Pencil for scale. C, D, E – back-scattered electron images of spessartite, a transitional spessartite/micromonzodiorite and micromonzodiorite, respectively, showing typical textures and minerals. Details in text. Scale bar – 100 µm. Ab – albite; Am – amphibole (pargasite and edenite in phenocryst cores, magnesiohornblende at phenocryst rims and in the groundmass); Bt – biotite; Chl – chlorite, Ap – apatite; Kf – K-feldspar; Pl – plagioclase; Prh – prehnite; Px – clinopyroxene (diopside); Q – quartz; Ttn – titanite.

Amphibole phenocrysts in the spessartites exhibit a greenish to olive and brown pleochroism, with dark cores and pale-coloured margins. The cores are usually pargasites or edenites. The pale-coloured phenocryst margins and the groundmass crystals are magnesiohornblendes. Most commonly, the chemical zoning is expressed by an increase in Si and Mg and a decrease of Na and K contents near the phenocryst rims. However, some crystals show more complex patterns in their inner parts, including oscillatory zoning, patches of variable composition, embayments and breccia-like textures. Some phenocrysts contain small veins or intergrowths of actinolite.

Amphiboles in the micromonzodiorites are less common, but more variable. Pargasite and magnesiohornblende compositions are most typical, but edenite, magnesiohastingsite, ferropargasite and ferrohornblende are not uncommon. Zoning patterns in some phenocrysts are similar to those seen the spessartite amphiboles, but several crystals show just a reverse pattern or more variable, oscillatory patterns.

Dark mica in both rock types is partly replaced by prehnite and chlorite with titanite inclusions. However, the relatively low Mg/(Mg+Fe) of ca 0.4 of the mica suggest biotitic compositions.

Clinopyroxene forms rare groundmass crystals in the spessartites, but phenocrysts in the micromonzodiorites. It is usually diopside and more rarely Ca-rich augite. Clinopyroxene phenocrysts in the micromonzodiorites contain relatively large 'dusty' cores with patches of variable composition and with numerous inclusions of alkali feldspar and apatite. Phenocryst margins are free of inclusions and exhibit oscillatory zoning.

Plagioclase is the main felsic mineral in the dyke rocks at Chwalisław. Groundmass plagioclase laths are up to ca 0.05 mm long in the spessartites and 0.1-0.15 mm long in the micromonzodiorites. In spessartites, the plagioclase is oligoclase to andesine in composition (An < 37). There are also plagioclase xenocrysts of similar composition, but strongly corroded, sieve-textured and with intergrowths of alkali feldspar. In the micromonzodiorites, the plagioclase is oligoclase to albite in composition (An < 27). Many plagioclase crystals are replaced by aggregates of Na-feldspar, K-feldspar, sericite and prehnite. In all of the Chwalisław dyke rocks studied, K-feldspar of composition typically close to Or90-93 is an abundant groundmass component. Graphic intergrowths of K-feldspar and quartz around groundmass plagioclase laths are characteristic of the micromonzodiorites.

Despite considerable petrographic variation, the whole-rock chemical composition of the spessartites and micromonzodiorites from Chwalisław is relatively uniform. These are intermediate/acidic rocks (SiO_2 ca 62-65%) of calc-alkaline affinity. The contents of MgO (6-3%), Cr (300-100 ppm) and Ni (100-50 ppm) and the Mg-numbers (75-65) are relatively high; the higher values are typical of the spessartites. The trace element characteristics are, in general, similar to other lamprophyres of the Złoty Stok Dyke Swarm (e.g., significant negative Nb and Ta anomalies in normalized trace element patterns and similar Zr/Nb). However, the Chwalisław rocks are enriched in SiO_2, show higher abundances of several incompatible trace elements, e.g., Zr and Nb, and tend to form separate trends on some geochemical plots.

The Chwalisław dykes have been previously described by Wierzchołowski (1977) and recently dated by Mikulski and Williams (this volume). The palaeomagnetism and albitization of the host granodiorites, and the palaeogeographic implications, were studied by Yao et al. (this volume). The site is therefore interesting from several viewpoints.

The dykes at Chwalisław show a specific form, characterized by the interdigitation between spessartites, micromonzodiorites and granites. This can be related to the emplacement of the mafic magmas into early fractures within incompletely solidified granites (cf. Barbarin 2005). Various degrees of mixing/mingling between the intruding mafic magma and residual granitic melts may be involved. At Chwalisław, the evidence for such interactions are granitic xenoliths and xenocrysts of quartz and plagioclase in the dyke rocks. However, the dominant petrographic features, including the variable phenocryst assemblages and the various zoning patterns in amphibole- and pyroxene phenocrysts in the spessartites and micromonzodiorites, likely reflect magma mixing processes in a deeper part of the magmatic system. The petrographic and chemical differences between samples taken from adjacent dykes may further suggest that the intruding mafic magma was not fully homogenized at the time of dyke emplacement. It may also be that the rocks at Chwalisław, geochemically- and petrographically distinct from the other ZSDS spessartites in various ways, are rocks showing the superimposed effects of two distinct magma mixing events at different levels of the magmatic systems.

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Geological setting of the Bystrzyckie Mts Crystalline Massif

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The Orlica-Śnieżnik Massif (OSM) is situated in the easternmost part of the Central Sudetes (Fig. 1). The western part of the massif, comprising the Bystrzyckie Mts Crystalline Massif and the Orlica Mts Crystalline Massif, is composed of a large orthogneiss body (the Bystrzyca- and Orlica orthogneisses, equivalent to the Śnieżnik orthogneiss) which is mantled by a metamorphosed volcano-sedimentary series composed mainly of mica schists, paragneisses, basic and acid metavolcanics and marbles (Fig. 2).

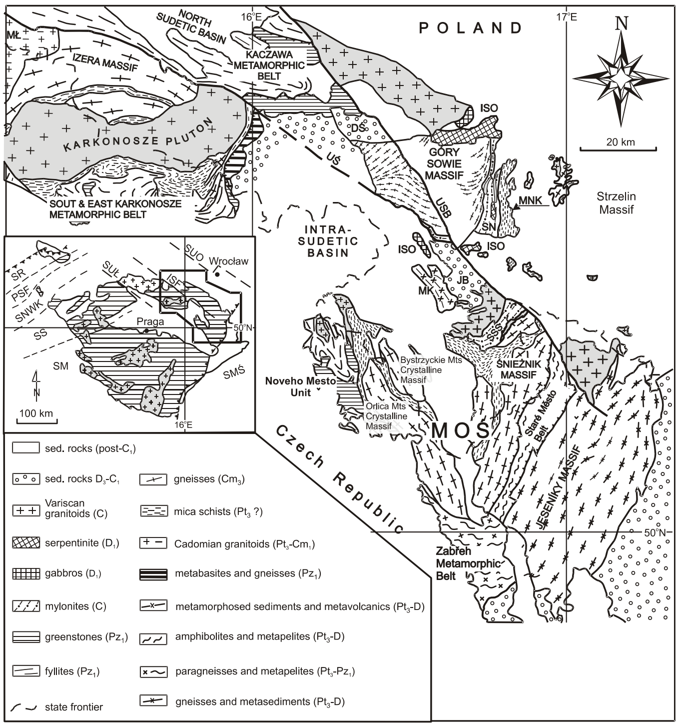

Fig. 1. Simplifed tectonic map of the Sudetes after Mazur et al. (2010). Abbreviations: DŚ – Świebodzice Basin, ISF – Intra-Sudetic Fault, ISO – Intra-Sudetic Ophiolite, JB – Bardo Structural Unit, MK – Kłodzko Metamorphic Massif, MŁ – Lusatian Massif, MOŚ – Orlica-Śnieżnik Massif, MNK – Niemcza-Kamieniec Metamorphic Belt, PSF – Northern Phyllite Zone, SR – Rhenohercynian Zone, SM – Moldanubian Zone, SMŚ – Moravo-Silezian Zone, SN – Niemcza Shear Zone, SNWK – Mid-German Crystalline Rise, SS – Saxothuringian Zone, SSS – Skrzynka Shear Zone, SUŁ – Upper Elbe Fault Zone, SUO – Middle Odra Fault Zone, UŚ – Inta-Sudetic Fault, USB – Sudetic Boundary Fault. Age assignments: Pt – Proterozoik, Pz – Palaeozoic, Cm – Cambrian, Or – Ordovician, D – Devonian, C – Carboniferous, 1 – Early, 2 – Middle, 3 – Late.

Three main tectonic units, bearing records of contrasting metamorphic paths, have been identified in the Bystrzyckie Mts Crystalline Massif (from base to top): the Poręba, Młoty and Niemojów Units (Szczepański 2010). Upper part of each tectonic unit consists of orthogneiss, whereas the lower portion is composed of the supracrustal succession.

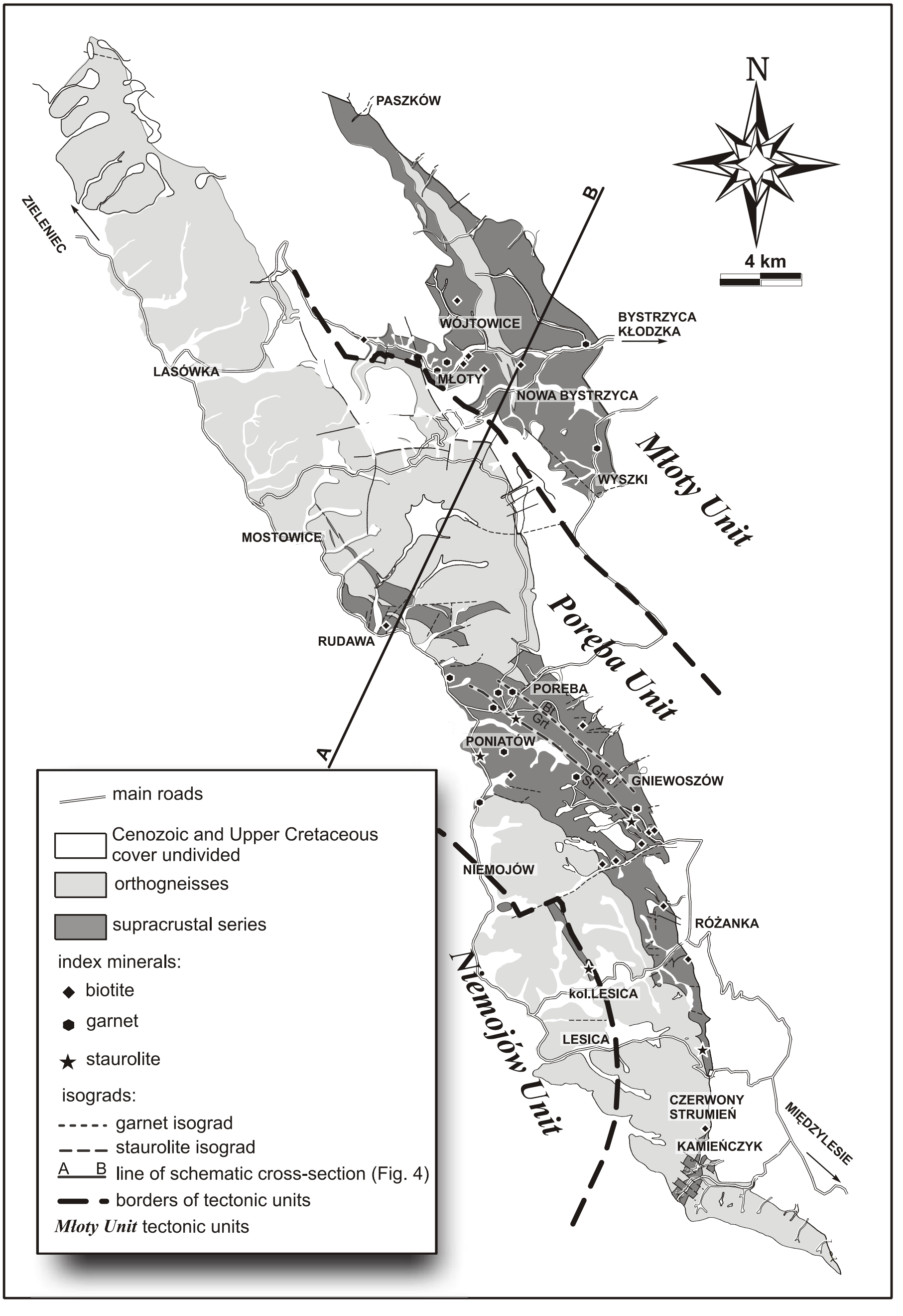

Fig. 2. Geological sketch map of the Bystrzyckie Mts Crystalline Massif showing index minerals and isograds.

The succession shows different lithological compositions in each tectonic unit. The Młoty Unit comprises paragneisses with minor intercalations of mica schists and metabasites. The supracrustal series of the Poręba Unit consists of mica schists interlayered with abundant paragneisses, metabasites, marbles and quartzites. In the Niemojów Unit only mica schists and quartzites are present. The chemical composition of metasedimentary rocks making up the main part of the supracrustal succession suggests derivation of its protolith from an active continental margin (Fig. 3; Szczepański 2010 and abstract in this volume). Therefore, the metasediments must have been deposited in a suprasubduction tectonic environment. Available data on the chemistry of metabasites from the supracrustal series show geochemical characteristics that may be indicative of a back-arc basin environment (Nowak and Żelaźniewicz 2006, Szczepański and Ilnicki 2009a, Ilnicki and Szczepański 2009b).

The tectonometamorphic evolution of the area involved four deformation and metamorphic events (Szczepański 2006). The effects of the oldest tectonometamorphic event most probably predated or were coeval with intrusion of the orthogneiss protolith. Two succeeding events document the Variscan evolution of the Sudetes.

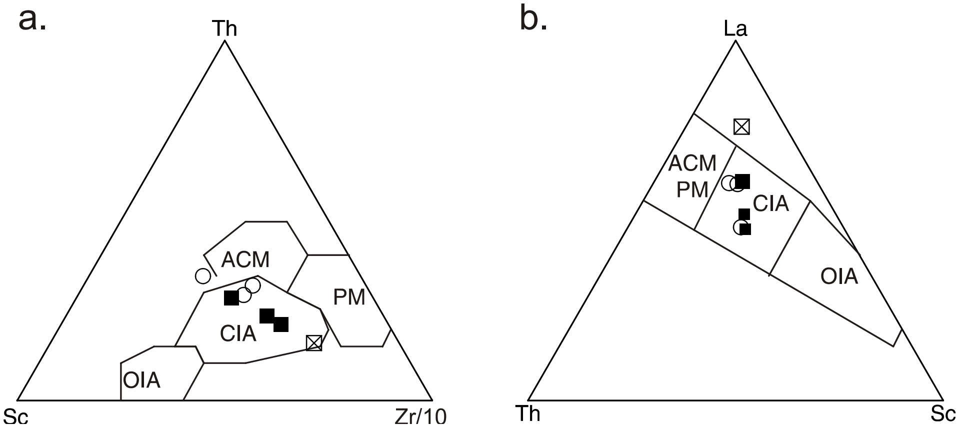

Fig. 3. Discrimination diagrams: a) Sc-Th-Zr/10 and b) Th-La-Sc after Bhatia and Crook (1986). Abbreviations: CIA – continental island arc, OIA – oceanic island arc, ACM – active continental margin, PM – passive continental margin. Symbols: black squares – paragneisses, empty circles – mica schists. Empty square with cross inside – sample s45A.

The first of these was related to crystalline nappe emplacement and folding (Fig. 4). The metamorphic record (M_2) synchronous with this event documents an increase of temperature and pressure (Fig. 4).

The highest pressures were obtained for the structurally highest Niemojów Unit, the lowest pressures for the structurally lowest Poręba Unit. The third deformation event was possibly associated with dextral strike-slip shearing along the contact of the Teplá-Barrandian and Moldanubian terranes at 340 Ma (Fig. 5). The final phases of this event involved gravitational collapse of the previously thickened nappe pile and was related to metamorphism with biotite, garnet and staurolite zones (Szczepański 2002). Isograds resulting from this metamorphism generally trend parallel to the border between the Nové Město Unit and Orlica-Śnieżnik Massif (Fig. 4).

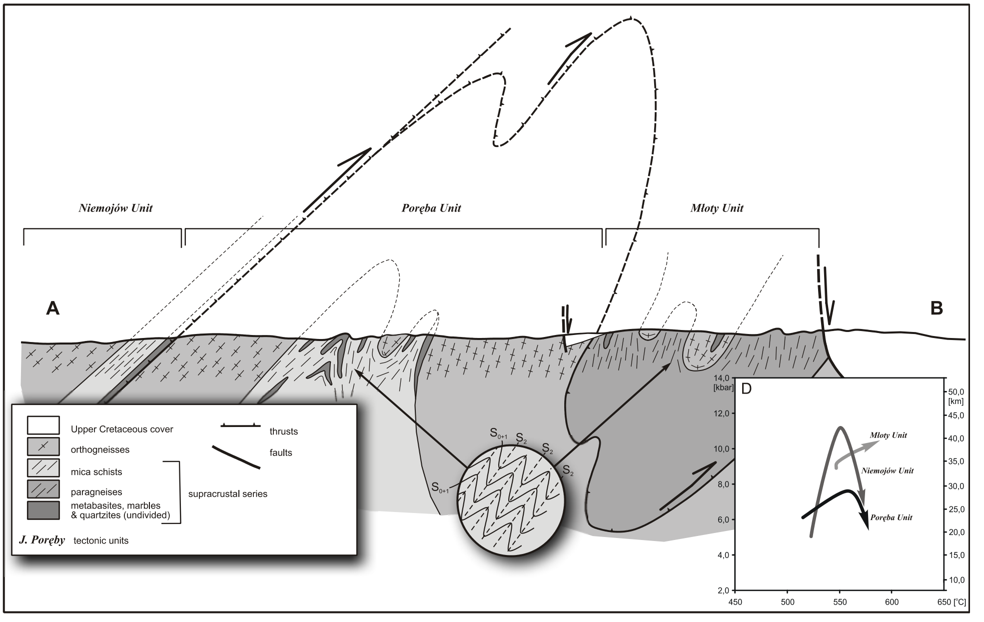

Fig. 4. Schematic NE-SW oriented cross section of the Bystrzyckie Mts showing the relationships between the tectonic units. Location of the section line is given in Fig. 2. Also shown are PT paths reconstructed for metasediments from different tectonic units.

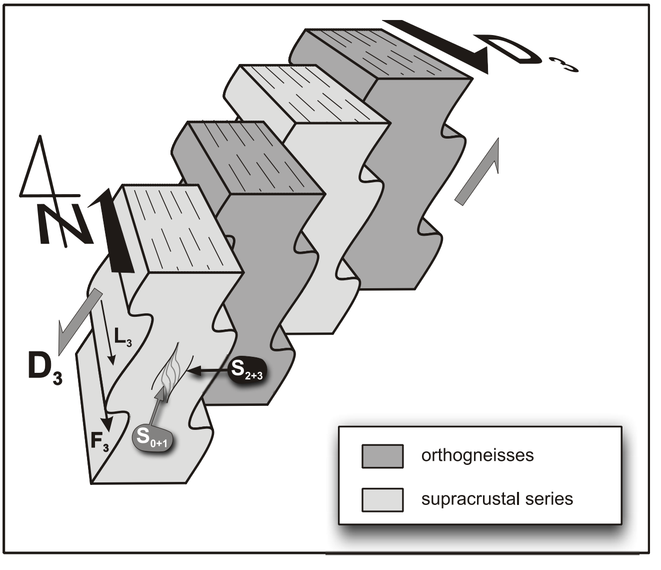

Fig. 5. Cartoon showing deformation structures developed during deformation D3.

The metamorphic grade decreases outwards from the central part of the Bystrzyckie Mts. The zonal pattern of metamorphism presumably resulted from two factors: (a) juxtaposition of tectonic units carrying different records of the M_2 metamorphism and (b) exhumation of rock complexes that experienced a higher temperature metamorphic overprint in the central part of the Bystrzyckie Mts. The last tectonometamorphic event, a brittle-ductile event, could have been linked to the final phases of the Variscan, or even Alpine, orogenies.

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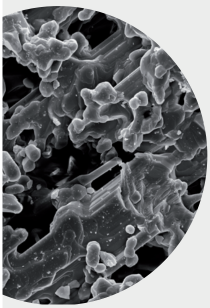

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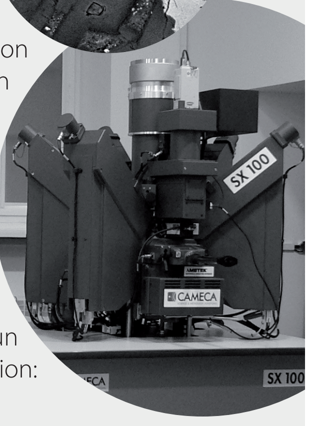

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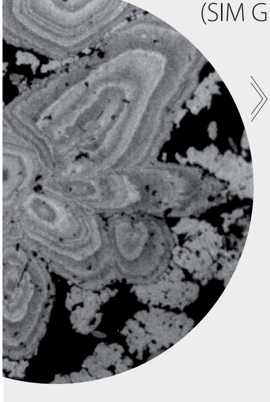

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