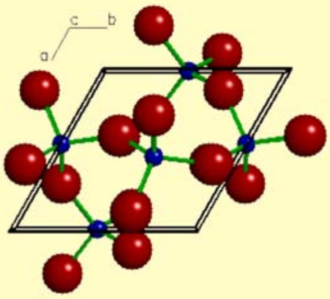
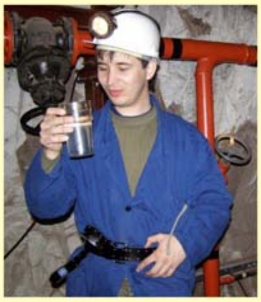
SGA Student Conference

Prague, Czech Republic
15 - 19 April 2011

Mineral resources for the society

Abstract Volume
Field trip Guidebook





Society for Geology Applied to Mineral Deposits
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Faculty of Science, Charles University in Prague

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Prague, April 15-19, 2011

ABSTRACT VOLUME

&

FIELD TRIP GUIDEBOOK

Editor

Kateřina Schlöglová

Contents

Program of the conference

April 15, Friday

17:00 *Registration* - Check-in desk, entrance hall of the Department of Geology, Faculty of Science, Charles University (Albertov 6, Prague 2)

19:00 *Ice-breaker Party* - Chlupáč Museum of the Earth and Life History, Faculty of Science

April 16, Saturday

8:00 – 9:00 *Registration* - Check-in desk, entrance hall of the Department of Geology
Uploading of presentations (lecture hall VG, Velká Geologická posluchárna)
Poster mounting (central hall, 1st floor)

9:00 – 9:10 *Invitation by Vice-Dean of the Faculty of Science, Charles University – Vojtěch Ettler, and by SGA Executive Secretary – Jan Pašava* (lecture room VG – Velká Geologická posluchárna)

9:10 – 10:30 *Plenary lecture by SGA invited speaker:*

Prof. Pär Weihed (Luleå University of Technology, Sweden)
Precambrian VMS and gold with case studies from the Fennoscandian Shield

10:30 – 11:00 *Coffee break* (room LS, Ložiskové sbírky, 1st floor, right sector)

Oral session: Ore deposits of magmatic and metamorphic terrains

11:00 – 11:15 Nadejda Shatova
High potassium intrusive rocks of the Ryabinovy stock (South Yakutiya) and associated Au-Cu porphyry style mineralization

11:15 – 11:30 Wladyslaw Zygo
Tsagaan Tsakhir gold deposit: geology and mineralization, Mongolia

11:30 – 11:45 Mira Valkama
Polymetalic veins in the western parts of the Wiborg Rapakivi Batholith, southeastern Finland

11:45 – 12:00 Thomas Dittrich
Geology and mineralization of the polymetallic Salt River deposit near Poffader, Namaqualand metamorphic province, South Africa

12:00 – 13:30 *Lunch in a local pub*

13:30 – 15:00 *Plenary lecture sponsored by IGCP 540 project:*

Dr. Jiří Zachariáš (Charles University in Prague)
Orogenic gold deposits in the Bohemian Massif: review and case studies

15:00 – 15:15 *Coffee break* (room LS)

Oral session: Hydrothermal mineralization styles

15:15 – 15:30 Nikola Denisová
The Kombat deposit in Namibia: A possible IOCG deposit

15:30 – 15:45 Tomasz Cwiertnia
Geochemical exploration for base and precious metals, Bayankhongor province, Mongolia

15:45 – 16:00 Matylda Heřmanská
Reactive fluid flow and origin of fracture-controlled greisens in the Krušné Hory Mts., Czech Republic

16:00 – 16:15 Lukáš Vondrovic
Origin of wolframite mineralization at Jeřmanice, central Europe: evidence from mineral chemistry, fluid inclusions, oxygen stable isotopes and Re-Os geochemistry

16:30 – 17:30 *SGA Student Chapters meeting* (coffee room LS, 1st floor, right sector)

20:00 *Social evening* "Prague by night" organized by the Prague Chapter students

April 17, Sunday

8:15 – 8:30 *Uploading of presentations* (lecture hall VG)

8:30 – 10:00 *Plenary lecture by SGA invited speaker*:

Prof. Bernd Lehmann (Technical University of Clausthal, Germany)
Diamond deposits in general, with a case study from India

10:00 – 10:30 *Coffee break* (coffee room LS)

Oral session: Mineralogy and crystal chemistry

10:30 – 10:45 Jan Soumar
Crystal chemistry and structure refinement of pyralspite garnets from the Shavaryn Caram deposit in Mongolia and of the "Bohemian Garnets"

10:45 – 11:00 Vladimír Čavajda
Qualitative and quantitative analysis of talc from Western Carpathians

11:00 – 11:15 Nikola Heroldová
Low-temperature alteration of metamict Y, REE, Nb, Ta, Ti-oxide minerals

11:15 – 11:30 Jakub Plášil
The role of Y^{3+} and REE in the crystal structures of the zippeite group minerals

11:30 – 11:45 Friederike Minz
Cement stratigraphy of the footwall rocks bellow the Kupferschiefer from the Cu-Ag deposit Spremberg-Graustein, Germany

11:45 – 13:15 *Lunch in a local pub*

13:15 – 14:15 *Plenary lecture sponsored by IGCP 540 project:*

Dr. Peter Koděra (Comenius University in Bratislava, Slovakia)
Actual problems of metallogeny in Slovakia: Au-porphyry mineralisation at Biely vrch and Kremnica hydrothermal system

14:15 – 15:45 *Poster session* (central hall, 1st floor), c*offee break included*

Oral session: Environmental aspects of mining

15:45 – 16:00 Katarína Peťková
Mineralogical and geochemical evaluation of soils contaminated by arsenic-rich coal fly ash

16:00 – 16:15 Marián Petrák
Preliminary results of geochemical investigation of tailing impoundment at Markušovce, Slovakia

16:15 – 16:30 Kristína Mangová
Reclamation of sulphide mine tailing in an abandoned ore deposit, Smolník

17:00 *Presentation of the best student oral and poster awards*

Field trips itinerary

April 18, Monday – Příbram, field trip is led by Pavel Škácha

7:30 *Departure from the Faculty of Science*

Dump of the Březové Hory concentrator, mineral exhibition in the Příbram mining museum, Drkolnov mine with a unique water wheel, Uranium shacktown in Vojna, mineralogy of uraniferous ore dumps

Return to Prague in late afternoon (ca. 18:00)

April 19, Tuesday – Jáchymov, field trip is led by Jakub Plášil

Optional field trip, fee 20 EUR – including transport, entrance fees to museums and mines and field trip dinner in Chyše (any other consumption will be paid by participants privately)

6:00 *Departure from the Faculty of Science*

Svornost mine and museum of mining and history in Jáchymov, Bathhouse Radium Palace, excursion to the outcrop parts and mine dumps of the Schweitzer and Geister vein deposit, former labour camp Rovnost, Rovnost pit, Eliáš valley with old mining pond and Eliáš pit, Brewery´s pub in Chyše – guided tour and dinner

Return to Prague in late afternoon (ca. 20:00)

Important note

Please wear appropriate boots and clothing for both field trips. Coat, hardhead and light will be provided in the mines. Lunch will be provided by the lunch boxes. Departure and arrival time may change slightly according to actual tour reservations. More information will be provided during the conference.

ABSTRACT VOLUME

Hydrotermal Alteration and Mass Change Calculations at the Mastra Au-Ag Deposit, Gümüşhane, Turkey

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The Mastra Au-Ag deposit is situated near the Demirkaynak village, 5 km to the northwest of Gümüşhane. In this area, which is mainly formed by andesitic volcanics and volcaniclastic rocks of Eocene age, the ore zone is composed of quartz veins within a fault zone striking N50-70^0 W and dipping 65-80^0 NE. The veins are about 2.5 km long and a few cm to 5 m wide. Native Au, Ag, pyrite, chalcopyrite, sphalerite, sulphosalts, galena, digenite, and covellite/chalcosite are the main ore minerals, whereas quartz, barite, adularia, calcite, cerusite, gypsum, hematite, limonite, sericite, and clay minerals are the gangue minerals. Quartz is the most abundant among the gangue minerals and the main constituent of the veins.

Hydrothermal alteration is represented mainly by chloritisation, carbonatisation, epidotisation, sericitisation, silicification and clay alteration. These alteration minerals are found in different combinations and form, from the outer zones to inner zones of the deposit: a) propylitic alteration zone, (b) argillic alteration zone, and (c) silicification zone. The propylitic zone varies in composition from mainly chlorite and clay minerals, and carbonates to a lesser extent at the outer zones, and carbonates and clay minerals, and chlorite to a lesser extent at the inner zones.

Mass change calculations applied to the Mastra deposit, during the formation of which Zr behaved as an immobile element, indicate that hydrothermally altered rocks were subjected to mass and volume increases as a result of hydrothermal fluid and rock interactions. The mass and volumetric changes in the outer zone of the propylitic alteration zone, represented by chlorite-clay minerals ± carbonates are about 30 g/100g. Towards the inner zones aproaching the argillic zone the change increases up to 42.01 g/100g. The argillic zone displays a volumetric change (25.17 g/100g) that is similar to the outer propylitic zone. The highest changes are estimated in the silicified zone, the center of the alteration halo (4157 g/100g). Si, Fe, Mg and K are the elements with the highest positive changes in the outer propylitic zone; Fe, Mg, Ca and K in the inner propylitic zone, Si, Al and K in the argillic zone, and Si, Al, Fe and K in the silicified zone.

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MacLean, W. H. & Kranidiotis, P., (1987) Immobile elements as monitors of Mass Transfer in Hydrothermal Alteration: Phelps Dogge Massive Sulfide Deposit, Matagami, Quebec. Econ.Geology, 82, 951-962.

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Qualitative and quantitative analysis of talc from Western Carpathians

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Economic accumulations of talc in Slovakia belong to the deposits in association with Mg-carbonates. The main deposits were evolved in Veporic unit (Early Paleozoic Sinec belt) and in Gemeric unit (Early Paleozoic Gelnica group) (Grecula et al., 2000). One of the most serious negative factors affecting the quality of talc material is Fe content. Fe may occur directly in a talc structure but mostly in contaminants like chlorite, pyrite, and carbonate minerals. The RockJock is a program used for determining quantitative mineralogy from powder x-ray diffraction data (Eberl, 2003). This data can give us accurate information about percentage representation about individual mineral phases presented in rock. Results from XRD quantitative mineral analysis, showed that amounts of talc from Gemerská Poloma samples vary from 90 % to 25 %. Samples from Hnúšťa - Mútnik contain 85-1 % of talc. Other minerals are chlorite, quartz, magnesite, dolomite, biotite, muscovite (illite), and pyrite. Quantitative XRD analysis of talc brings some problems, which are connected with preferential orientation of their crystals. To fix this problem we used McCrone mill to achieve possible homogenization (Środoń, et al., 2001). To reduce intensity of talc XRD patterns we also used spray – dried technique (Hillier, 1999). The set of talc and pyrite mixtures were used to support the accuracy of analyses. We observed a systematic error, which was removed after changing of mean particle size from 6 to 20 microns in Rietveld analysis. We assume that prolonged grinding time will correct the systematic error. Structural and chemical characterization of talc was also performed by IR spectroscopy, electron microprobe, ICP.

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The Kombat Deposit in Namibia: A possible IOCG deposit

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The Kombat Deposit in Namibia shares some features similar with iron oxide copper gold (IOCG) deposits. The most striking feature is the occurrence of both oxide (magnetite, hematite, hausmannite) and sulfide (chalcopyrite, bornite, galena mineralization). The IOCG deposits form a broad group of world-class deposits characterized by economic grades of copper and gold, the presence of abundant magnetite and hematite, the regional scale of alteration and association with breccia bodies and shear zones (Groves et. al., 2010)

The Kombat deposit is situated in Namibia, in the Otavi Mountainland metallogenic province. The Cu-Pb-Ag mineralization occurs in dolostones of the Hüttenberg Formation, in overlying phyllites of the Kombat Formation and in sandstones of the Mulden Group. The sandstones represent an infill of the carstified Hüttenberg Formation paleosurface. Localization of the ore bodies is controlled structurally (tectonic breccias and shear zones related to deformation phases of the late Proterozoic Damaran Orogeny) (Innes & Chaplin, 1986). There are two types of hypogene mineralization at the Kombat deposit: (i) sulfide mineralization (chalcopyrite and bornite; galena; galena and pyrite) related to the dolostone/slate contact and with the sandstone bodies, sedimentary and tectonic breccias and fractures in altered dolomite; and (ii) compositionally layered Fe-Mn oxide/silicate assemblages of magnetite, hematite, and hausmannite closely associated with the sandstone bodies (Innes & Chaplin, 1986).

The genetic model for the deposit is unclear, varying with each author. The most recent genetic model of Frimmel et. al. (1996) proposes that the Fe-Mn oxide/silicate assemblage was deposited in shallow, oxidic waters, while the first stage of the sulfide mineralization was deposited in a deeper, anoxic environment during extension of the basin. During subsequent continental collision, metal-bearing fluids were expelled from underlying basement rocks and trapped along the contact with a sulfur-rich horizon in the Hüttenberg formation.

So far no one considered the Kombat deposit likely to be of the IOCG type. Although the deposit does not possess some of the attributes of typical IOCG deposits (e.g., temporal association with magmatism, regional scale of alteration, tectonic position), some of its features (mineralogy, fluids, structural control) allow us to advocate the IOCG model of formation as an alternative to previous models.

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Geology and mineralization of the polymetallic Salt River deposit near Pofadder, Namaqualand metamorphic province, South Africa

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The stratabound Salt River base metal deposit and related prospects define a narrow E-W oriented trend in the SE portion of the Mesoproterozoic Namaqualand Metamorphic Province of Northern Cape Province, South Africa. The Namaqualand Metamorphic Province represents a structurally controlled belt composed of Paleoproterozoic to Mesoproterozoic poly-deformed, greenschist- to granulite-facies, meta-sedimentary and meta-igneous rocks (Joubert, 1971).

The Salt River deposit forms a massive pyrite body that remains open down plunge to at least 3000 m or roughly 1300 m below surface. Currently known total mineral resources comprise 26 Mt at 1.76% Zn, 0.64% Cu, 0.49% Pb, 22 g/t Ag and 0.84 g/t Au with a high grade zone measuring 12 Mt at 2.2% Zn, 0.7% Cu, 0.6% Pb, 30 g/t Ag and 1 g/t Au (McClung, 2008, pers. comm).

The host rock sequence of the Salt River deposit comprises three main rock types: (i) grey gneiss, (ii) amphibolite, and (iii) granitic augengneiss. The mineralised section consists of semi-massive to massive sulphide and two types of alteration lithotype, namely the biotite-quartz hydrothermal rock and biotite-cordierite gneiss.

Petrological and geochronological studies revealed that this sequence was subjected to typical MP/MT Barrovian regional metamorphism during the Namaquan Orogeny (Clifford et al., 2004). The metamorphism was dated at 1146 ± 6.4 Ma by the EMP-Th-U-Pb monazite method and developed under prograde metamorphic conditions from upper greenschist facies (482°C and 2.9 kbar) to upper amphibolites facies (700°C and 7 kbar) as reconstructed by amphibole geothermobarometry. Monazite geochronology also documented a second metamorphic event that affected the succession at 1035±11 Ma. This is likely related to the intrusions of the Spektakel, Koperberg or Wortel Suites that intruded into the Bushmanland Terrane during the Klondikean event of the Namaquan Orogeny (Clifford et al., 2004). This was immediately followed by exhumation at 971 ± 6 Ma, accompanied by small scale decompressional intracrustal melts causing intrusions of pegmatites, retrograde mineral reactions and renewed growth of monazite. The late retrograde metamorphism is characterized by intense sericitization of plagioclase, chloritization of biotite and probably pinitization of cordierite.

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Application and significance of Vickers Microhardness Measurments for coal

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The reserves of coal account for 64.8 % of fossil fuel worldwide. Therefore coal is still an option of energy supply in the future. For that reason the optimization of production and conditioning of coal are of great importance. The classification of grindability belongs to the essential technological characteristics that determine further treatment of coal. It is of practical and economic interest for the choice, size and wear of the machines. Up to now, the Hardgrove grindability index (HGI) is the most-established method to specify the grindability. In the past there have been several attempts to replace this complex and inappropriate method by the application of Vickers microhardness tests (MHV).

The Vickers procedure utilizes a diamond pyramid with rectangular cross section, which indents with constant proof load perpendicularly to the coal surface. After the indenter is lifted again the remaining pit is measured to calculate the MHV. It is obtained from the ratio of proof load and indent area.

Microhardness studies can only lead to reasonable results if they are applied on polished surfaces of pure macerals. They feature the necessary homogenity to minimize the influence of anisotropy leading to undesired deformation and cracks. Vitrinite meets such criteria. After a sufficient number of statistically independent tests have been done, the macrohardness of seams is determined with the help of a mixing rule. Several aspects of sample preparation and characterization of the specimen affect the MHV. Shocks and vibrations during the measurement exert a dominating influence as well. Moreover, the degree of carbonization causes elasticity which distorts the indent at a level of more than 92 % carbon (anthracite).

With the help of scientific research, MHV can be a simple and rapid alternative to the HGI. The method after Vickers requires only little effort and delivers results with a statistically better resolution than the HGI. As the constitution of the specimen limits the possibilities of investigation tests that have been done with vitrinite yet. It is advisable to extent measurements after Vickers to other microlithotypes in order to gain a more detailed knowledge about microhardness behavior of coal.

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Reactive fluid flow and origin of the fracture-controlled greisens in the Krušné hory Mts., Czech Republic

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Saxothuringian zone of the Variscan orogen in central Europe hosts numerous granitic intrusions associated with hydrothermal alteration and Sn-W mineralization. The Horní Blatná body is a composite intrusion, which consists of several intrusive units of highly evolved peraluminous, Li- and F-rich granites of S-type. These varieties range from porphyritic biotite granites to fine-grained equigranular Li-mica granites. Four intrusive units are cross-cut by veins and swarms of fracture-controlled greisens up to 400 m long and 800 m deep, which exhibit the following alteration zoning (inward): greisenized granite, muscovite-quartz greisen, topaz-quartz greisen, pure quartz greisen, and hydrothermal quartz vein. Younger hematitization is locally superimposed on the greisen alteration. Textures of the greisens, in particular the distribution and shapes of relics of quartz phenocrysts, suggest that greisenization was essentially a constant-volume replacement process and it resulted from low-salinity, CO_2-free aqueous fluids near 400 °C and 500 bar, revealed by fluid inclusion studies. In the second stage, quartz veins with euhedral crystals and cavity fillings precipitated when the greisen zones re-opened. We propose a thermodynamic transport model to simulate the progress of alteration reactions and to estimate the fluid fluxes necessary for the formation of the spatial zoning. In this model, we evaluate the disequilibrium fluid infiltration and the pressure-temperature gradients simultaneously. Using a series of initial conditions, from 650 °C and 1 kbar (magmatic fluid phase exsolving at the solidus) to 400 °C and 500 bar (conditions of greisen formation), the formation of muscovite-quartz greisens requires a time-integrated flux of $\sim 10^2$ to 10^5 m^3 fluid per m^2 rock, whereas the formation of topaz-quartz greisens is predicted to occur at $\sim 10^2$ to $\sim 10^6$ m^3 fluid per m^2 rock. The fluxes can be further specified by constraining permissible modal variations and volume changes. For the volume-conserved replacement to occur, the integrated fluid flux could not have exceeded $\sim 10^3$ m^3 fluid per m^2 rock. In addition, the incoming fluids must have been in disequilibrium with the host rocks (originating at T = 480 °C or higher) in order to produce topaz-bearing alteration assemblages. For a conservative estimate of the time-integrated fluid flux on the order of 10^2 to 10^3 m^3 fluid per m^2 rock, the plausible flux rate is $\sim 10^{-10}$ to 10^{-8} m s^{-1}. Thus the formation of a single greisen vein with a typical volume of 10^3 to $5 \cdot 10^4$ m^3 would require 10^5-$3 \cdot 10^7$ m^3 aqueous fluid. By using mass balance and an assumed 5 wt. % H_2O dissolved in a granitic magma, such amount of fluid phase would have exsolved from $5 \cdot 10^5$ to $3 \cdot 10^8$ m^3 magma, or an intrusion measuring ~80 to 700 m in each dimension. These estimates are comparable with dimensions of intrusive units of the Horní Blatná body.

Low-temperature alteration of metamict Y, REE, Nb, Ta, Ti oxide minerals

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Y, REE, Nb, Ta, Ti-oxide minerals commonly contain significant amount of U and Th. The decay of radioactive elements causes fundamental changes to their physical and chemical properties. The process of metamictization is responsible for the structural damage and transformation of minerals from crystalline to amorphous matter (e.g. Ewing et al. 1987). During metamictization, the chemical durability decreases and these minerals lightly underwent hydrothermal alteration (Cherniak & Watson 2001; Geisler et al. 2003). Y, REE, Nb, Ta, Ti-oxide based ceramics has been considered to be a candidate for immobilizing various high-level wastes containing fissile elements (e.g. Ewing et al. 2004). Understanding of the alteration process and element mobility may be important for long-term nuclear waste repository.

Chemical composition of metamict aeschynite group minerals (orthorhombic AB_2O_6, where A-Y, REE, Ca, U and Th, B-Ti, Nb, Ta) from NYF pegmatite of Třebíč Pluton was studied in detail with an electron microprobe. The metamict state was confirmed by XRPD; the calculated absorbed radiation dose is ~$1.04.10^{19}$ α-decay events/mg. These minerals are heterogeneous in BSE images and show typical features of low-temperature alteration. The unaltered (the least altered) parts yields sum of oxides ~98 wt. % and A:B ratio close to 1:2. The altered areas are darker in BSE and obviously more hydrated; the sum of oxides in alterated areas decrease from 94.4 to 91.2 wt. %. The alteration is followed by gradual depletion in Y and REE, enrichment in Ca (from 3.7-5.0 wt. % CaO), enrichment in U and Th (from 4.81 to 12.13 wt. % $UO_2 + ThO_2$) and entrance of Fe and Si (≤ 0.57 wt. % FeO and ≤ 3.0 wt. % SiO_2). Among the B-site cations the Ti is relatively enriched and Nb+Ta are depleted in the altered zones. The ratio U/(U+Th) increase with increasing alteration. The most hydrated parts (the sum of oxides ~ 84 wt. %) show significant enrichment in SiO_2 (≤ 14.1 wt. %), FeO (≤ 31.9 wt. %), P_2O_5 (≤ 2.5 wt. %), ZrO_2 (≤ 3.2 wt. %) and PbO (≤ 2.3 wt. %) whereas the Y and REE are completely removed and the sum of $UO_2 + ThO_2$ decrease to ~ 5 wt. %. Thorium and uranium tend to be incorporated in the less to medium altered parts, but in the strongly altered areas are depleted. During the alteration the LREE are leached preferentially.

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Grade and tonnage model for orogenic gold deposits in Finland and comparison with Swedish, Zimbabwean, and Australian Southern Cross deposits

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Grade and tonnage models were constructed for Finnish orogenic gold deposits and results were compared with Swedish, Zimbabwean, and Australian Southern Cross deposits. Models are constructed by using tonnages and average grades of the whole deposits and data must form reasonable frequency distribution, typically a lognormal curve. Such models help to classify known deposits and provide information about the potential value of undiscovered deposits in a region. The models were constructed as part of Geological Survey of Finland's project National Resources of Useful Minerals, which aims at estimating the total resources of gold, copper, zinc nickel, platinum, and palladium in the Finnish bedrock down to one kilometer depth. This assessment will employ the three part quantitative mineral resource assessment method developed by USGS.

From the genetic point of view, majority of Finland's gold endowment consist of orogenic deposits. The main gold provinces are the Neoarchean greenstone belt in eastern Finland, and the Paleoproterozoic Central Lapland greenstone belt and the Svecofennian Complex in southwestern Finland. Deposits suitable for grade and tonnage models require a comprehensive resource estimate and must be classified under same deposit type. Descriptive model was developed to facilitate the correct classification and to emphasize the identifying characteristics of the deposits. A total of 31 deposits, both of Archaean and Palaeoproterozoic age, from all three main gold provinces and were included in the grade and tonnage models.

The average geometric mean of gold grade and ore tonnage of Finnish orogenic gold deposit were found to be 2.79 g/t and 503 000 t, respectively. Grade and tonnages of Archaean and Palaeoproterozoic deposits were tested for statistic significance by Independent Sample T-test which showed no significance between the ages (p values are 0.804 and 0.538). Finnish deposit are similar with Swedish deposits in grade and tonnage comparison (p values are 0.254 and 0.087) but significantly different from Zimbabwean deposits (p values $<$ 0.001 and 0.001). Based on their average grade, the Finnish deposits are comparable with Australian Southern Cross deposits (p value = 0.861). However, Finnish deposits are smaller in tonnages when compared to Southern Cross deposits (p value = 0.003).

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Alteration styles and geochemical zonation at the Raitevarri Cu-Au occurrence, Karasjok, Norway

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The Raitevarri Cu-Au occurrence is situated 40 km south of the Karasjok village in Finnmark, Norway. The occurrence is hosted by the Raitevarri hornblende-plagioclase gneiss, a km-scale meta-igneous unit enclosed within the Palaeoproterozoic Karasjok greenstone belt. Two distinctly different types of alteration are recognized: (1) plagioclase-epidote-chlorite assemblage, associated with quartz-epidote veins with amphibole selvages and (2) phyllic alteration assemblage (quartz, muscovite, pyrite ± chlorite ± tourmaline), associated with quartz, muscovite, sulphide or quartz-tourmaline, sulphide ± muscovite ± chlorite veins. The phyllic alteration is associated with significant gains in Cu, Au, Mo, Ag, As, Bi, Se, and Te as well as losses in Zn, Cd, and Mn. On the other hand, Zn appears to be enriched in the least-altered gneisses. The metal zonation in the drilled profile 500 shows two central zones where Cu, Au, and Mo anomalies coincide. The Cu-Au-Mo-enriched zones are surrounded by zones with elevated Zn, Mn, and Cd concentrations. The interpretation is that the Cu-Au-Mo zones represent high-temperature proximal alteration, whereas the Zn-Cd-Mn zones represent a distal, lower temperature alteration.

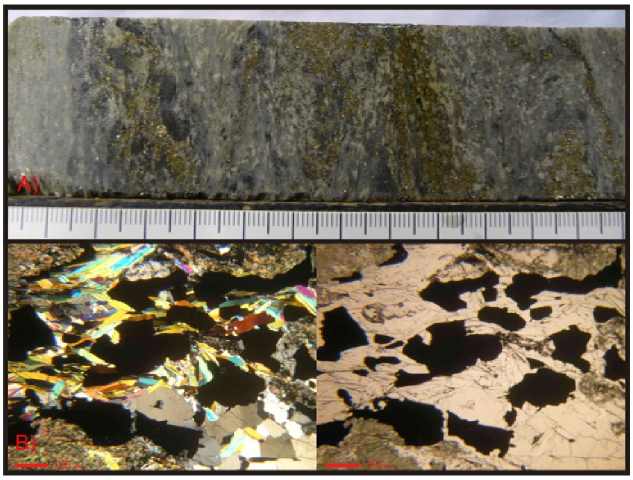

Fig. 1. *Drill core RAI-606 66.10 m.* ***(A)*** *Intense sericitic (muscovite) alteration with tourmalinisation and sulphidisation, and* ***(B)*** *coarse-grained quartz-muscovite-pyrite vein with tourmaline selvage.*

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Secondary minerals in mine tailings at several abandoned ore deposits in Slovakia

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Mineralogical composition of weathering products in mine wastes is an important factor that controls migration of pollutants (Ashley et al., 2003; Fillela et al., 2009). Results from 5 abandoned Sb-Au deposits (Čučma, Dúbrava, Medzibrod, Pezinok and Poproč) show differences in As and Sb behavior in the mine wastes. In most of studied localities, pH values of the tailing material are near-neutral because the acidity produced by sulfides decomposition is neutralized by abundant carbonates. Carbonates are scarce only at the Poproč deposit and the tailings here are acidic.

The most common sulfides in flotation wastes are pyrite and arsenopyrite, stibnite is rare probably due to its rapid oxidation. At all studied mine sites, oxidation rims on pyrite and arsenopyrite grains are developed and act as effective scavengers of As and Sb. Oxidation rims on pyrite contain up to 10.12 wt. % of As (Pezinok) and up to 7.5 wt. % of Sb (Pezinok); As content in rims on arsenopyrite is generally lower compared to the unaltered arsenopyrite grains, conversely Sb content is up to 14.3 wt. % (Čučma) and in one extreme case even 50 wt. % (Pezinok). The most rapid decomposition of pyrite and arsenopyrite was observed under acidic conditions (Poproč).

In general, as is sorbed onto Fe oxides. According to our μ-XRD data, Fe oxides with the low As content are made of goethite (Dúbrava, Pezinok and Poproč). When Pb is present in the pore solutions, Pb-As oxides with chemical composition close to beudantite $PbFe_3(AsO_4)(SO_4)(OH)_6$, mimetite $Pb_5(AsO_4)_3Cl$ and scorodite $Fe(AsO_4).2H_2$, are formed (Medzibrod). Antimony is most often present in form of Sb, Sb-Fe and Fe-Sb oxides and these may be the products of complete replacement of Sb ores or they may have precipitated from solutions which circulate through the impoundments. Antimony oxides were identified as stibiconite (Dúbrava) and cervantite (Poproč). Sb/Fe oxides were identified as tripuhyite $FeSbO_4$ at all localities. Sb oxides with various content of Ca identified as romeite $Ca_2Sb_2O_6(O,OH)$, are also common (Čučma, Dúbrava, Medzibrod and Poproč) and if Pb is present in the tailings, a mineral chemically close to bindheimite $Pb_2Sb_2O_7$, is formed (Medzibrod).

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Bukovskýite from medieval dumps at Kutná Hora, Czech Republic; An example of crystallization from Si-Al gel-like medium

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Bukovskýite (Fe^{3+}_2 $(AsO_4)_3$ $(SO_4)(OH)$ · $7H_2O$) was described as a new mineral from this locality (Novák, 1967). It occurs in medieval dumps at Kaňk village near Kutná Hora along with common Fe^{3+}-arsenates and sulphoarsenates (scorodite, parascorodite, kaňkite, zýkaite) and less common sulphates (gypsum, melanterite, jarosite, aluminite, alunogen, rozenite) as pale yellowish-white to grayish-yellow microcrystalline aggregates forming nodules commonly several cm across but locally up to ~1 m in size. Bukovskýite is a product of recent weathering of common sulphides arsenopyrite and pyrite. Field survey revealed two distinct As-rich mineral assemblages on the dumps: 1) scorodite-kaňkite-zýkaite aggregates (with no bukovskýite) in clastic gangue waste material, and 2) abundant bukovskýite with small nodules of parascorodite in clayish parts of the dumps. The almost monomineralic bukovskýite-rich zone commonly occurs ~ 1-2 m under the dump surface. The nodules studied primarily by EMPA revealed the crystallization of bukovskýite needle-like crystals from Fe, As, S-bearing Si-Al gel-like medium (10-82 wt. % SiO_2; 0.7-7 wt. % Al_2O_3; 1.7-24 wt. % Fe_2O_3; 2.2-19 wt. % As_2O_3, 1.2-4.6 wt. % SO_3; Σoxides 37-89 wt. %; Fig. 1. It is a product of dissolution of various minerals of the dump (Fig. 1) at strongly acidic conditions (pH = 2.4-3.9). This process may be related to the clays used during processing in medieval times.

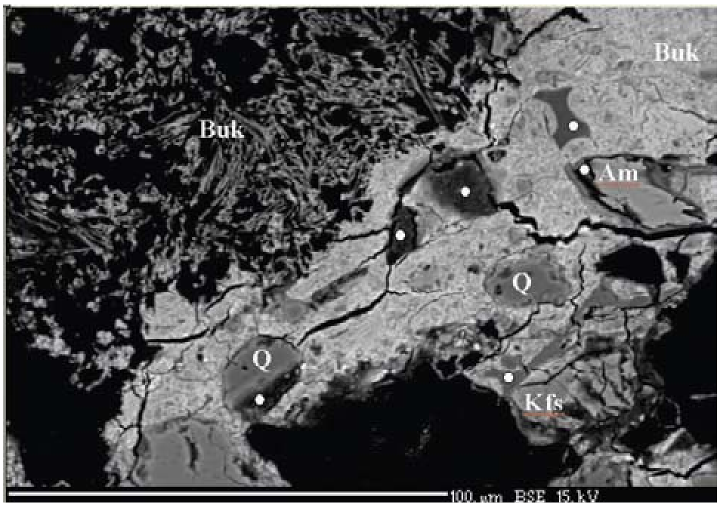

Fig. 1. *BSE image showing dissolution of various minerals and crystallization of bukovskýite from Si-Al gel-like medium. The light substance consists of partly crystallized bukovskýite (Buk), relics of minerals: Q = quartz, Kfs = K-feldspar, Am = Amphibole, and Si-Al gel-like medium (white dots).*

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Mineralogical and chemical study of fibrous tourmaline from Dolní Bory pegmatite, Czech Republic

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Minerals from tourmaline group due to their chemical and mechanical resistance and ability to incorporate large spectrum of elements provide a very good tool for interpretation of crystallization conditions. Tourmalines crystallize in many types of rocks and their morphology is highly variable including fibrous aggregates. Fibrous tourmaline was found in desilicated pegmatite near Dolní Bory, Western Moravia, Czech Republic. This ~3 m thick pegmatite dyke is situated at the contact between serpentinite and migmatitic gneisses. Here, graphic intergrowths of quartz and K-feldspar are typical but in most samples quartz has been completely dissolved. Desilication was caused by weathering of serpentinite and the cavities in K-feldspar are empty or filled with a green opal. Several types of tourmalines were recognized in the pegmatite: the first type is tourmaline surrounding biotite grains with Al_{tot} 4.73–5.75 apfu, high content of Fe_{tot} 1.85–2.47 apfu, Mg 1.1-1.37 apfu and a low degree of fractionation revealed by molar $Fe_{tot}/(Fe_{tot}+Mg)$ = 0.57-0.68. The second type is found in tourmaline veinlets in albite with Al_{tot} 5.5–5.98 apfu, Mg 0.29-0.84 apfu and higher degree of fractionation with $Fe_{tot}/(Fe_{tot}+Mg)$ = 0.74 – 0.90. The third type is represented by large grains with Al_{tot} 5.13–5.43 apfu, Fe_{tot} 1.99–2.49 apfu and even higher fractionation degree documented by $Fe_{tot}/(Fe_{tot}+Mg)$ = 0.62 – 0.83. Fibres overgrowing the latter type have high contents of Al_{tot} 6.07–6.37 apfu, $Fe_{(tot)}$ 0.96–0.99 apfu, Mg 1.57–1.62 apfu and generally very low degree of fractionation with $Fe_{tot}/(Fe_{tot}+Mg)$ ~ 0.38. The fibres are commonly enclosed in opal and represent the latest stage of tourmaline crystallization. It is an expected product of low-temperature hydrothermal activity near the end of differentiaion. The fibrous tourmaline has been studied by several authors (e.g. Novák et al., 1970; Yavuz et al. 1999) but our samples that are associated with opal are unique worldwide because they directly indicate crystallization at very low temperatures.

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Oil/gas seepage geochemistry at Turzovka, NW Slovakia; environmental impact

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The aim of this study is the geochemical characterization of small quantities of oil and natural gas coming out with water from a seepage situated in broader area of the Turzovka village in NW Slovakia (Korňa locality) as well as its environmental impact. This seepage was declared protected natural monument in 1984, however there are indices that it represents a remnant of abandoned wells from oil production activities between the two World Wars. The oil and methane release is rather small; nevertheless the degraded oil products are macroscopically manifested at the downhill water outflow as well as within the surface and subsurface soil horizons. Water/oil outflow reaches after about. 100 m the local creek Kornianka.

The investigated site belongs to the Magura nappe of Carpathian Flysh Belt. The Flysh formations are mainly represented by pelitic litologies with Cretaceous to Oligocene sandstone beds. Pelitic rocks exhibit high organic matter content, fertile source rocks are expected to occur rather in deeper parts. Paleozoic and Mesozoic fertile oil-producing source rocks were documented only in Czech Republic.

Former oil analyses indicate the presence of rather light n-alkanes mostly in C_{13} to C_{19} range. Generally, the aliphatic fraction is dominant over the aromatic one; the presence of oleanane proves its tertiary origin. Natural gas is according to the chemical and isotopic composition identified as thermogenic gas associated with oil production (Milička, 1999).

In summer 2010, samples of sub/surface water and soils were taken and analysed using gas chromatography on Agilent HP – 1530A apparatus in Czech Geological Survey, in Brno. Samples were taken downhill from water/oil/gas seepage from four regularly spaced sites towards the Kornianka creek. The aim is to assess the potential environmental impact, e.g. that is, how higher content of crude oil on the surface can effectively limit the growth of several herbaceous plants varieties (Lawrence et al., 2011). Other important aspect is the evaluation of potential contamination of the Kornianka creek and its alluvial sediments.

The study was supported by the project No. 1/0389/10 of Slovak VEGA grant agency.

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Reclamation of sulphide mine tailing in abandoned ore deposit Smolník

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Closed Cu- pyrite ore deposit Smolník is located in southern part of Slovenské Rudohorie between village of Smolnícka Huta and village of Smolník. For this project, we are interested in mine tailing impoundment in mentioned area, rehabilitated in 1998 by dry covering. Wood chips and sawdust – waste from nearby industry was used as material for reclamation. Tailing was planted with pines (Lintnerová et al., 2010b). This method of reclamation, however, ignored the major environmental risks of oxidation of pyrite, generation of AMD, iron, sulphates, Cu, As, Al and other hazardous elements documented by analysis of (1) drainage water and (2) elements in the surface layer of sulphide tailing at the depth of 1 meter (Lintnerová et al., 2010b). An important aspect of this process is the formation of secondary minerals, especially iron oxides. Fe oxides in soils have ability to change the surface properties of soil mineral components and affect the accumulation and quality of soil organic matter (Wagai & Mayer 2007; Wagai et al., 2009).

The aim of this study is to clarify the relationship between mineral and organic component in rehabilitated mine tailing for better understanding process of pedogenesis and mobility of hazardous elements by using these methods: mineral composition by X-ray diffraction**,** total sulphur and carbonate content**,** surface area measurement, paste pH, distribution of risk element using 0.5 M HCl in selected profiles.

Set of 90 samples was collected from tailing surface in three horizons, (surface 0-20 cm, middle 40-50 cm, bottom 80-100 cm). Sampling points were distributed in regular network, which extent has been 50 x 50 m.

Preliminary results show that the mobility of contaminants does not depend only on pH but also on surface properties of new form minerals and associations.

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Cement stratigraphy of the footwall Rocks below the Kupferschiefer from the Cu-Ag Deposit Spremberg-Graustein, Germany

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This study provides an insight into the diagenetic evolution of the Permian siliciclastic sedimentary rocks (PSSR) from the Spremberg-Graustein Cu-Ag deposit. Carbonate minerals form an important authigenic constituent of the PSSR. Cement stratigraphy has been used to reveal their diagenetic features. It involves investigation of zoning in carbonate minerals and correlation of these compositional zones in sedimentary rocks (Goldstein, 1991). Electron microprobe analysis, scanning electron and cathodoluminescence (CL) microscopy were applied in this study. The following four zones have been established in the dolomite-type carbonate minerals (Dcm I to IV, Fig.1 A): Dcm I (~ stoichiometric dolomite with Mn-enriched zones), Dcm II (~ 5 wt. % Mn, 2.5 wt. % Fe), Dcm III (~ 1.5 wt. % Mn, 9.5 wt. % Fe), and Dcm IV (~ 1.5 wt. % Mn, 7.5 wt. % Fe). The Fe concentration of Dcm III can be as high as 13 wt. %. Frequently, the Fe-rich Dcm displays microscopic features typical for saddle dolomite, which is assumed to have precipitated from saline, evolved basinal fluids (Spötl & Pitman, 1998). In the PSSR adjacent to the Kupferschiefer, Dcm I cement surrounds all detrital particles of the PSSR and Dcm II to IV form “vuggy carbonates” (Fig.1. A1). Downward the PSSR, Dcm I forms the cores of interstitial Dcm (A2) and bright to dull luminescent calcite becomes an important cement phase (Fig.1. B and C). Cu-sulphide minerals are associated with Dcm III and IV in the non-red PSSR.

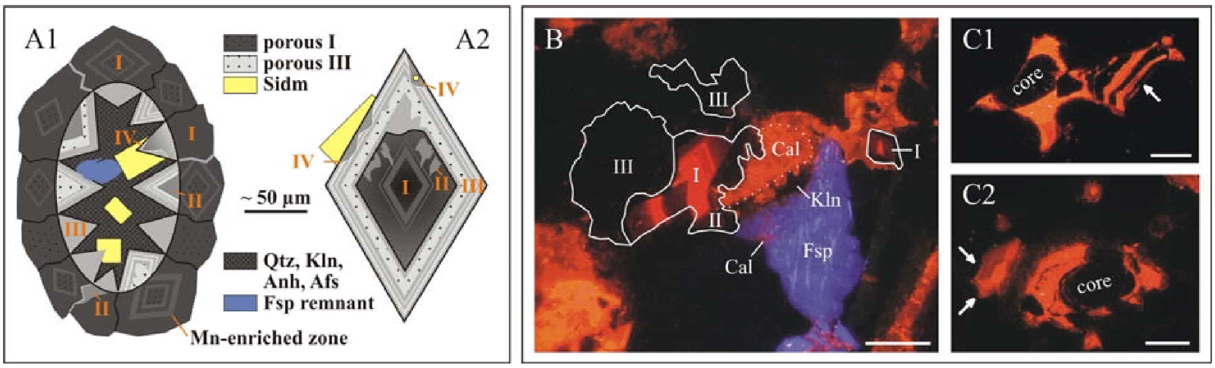

***Fig. 1. (A1, 2)** Zoning pattern of Dcm and its relation to sulphide minerals (Sidm); (**B**) to (**C**): CL photographs, scale bar 100 µm; (**B**) relation of Dcm I to III and bright luminescent calcite in the red PSSR; (**C1**) non-luminescent calcite cores and concentric zoned calcite (→), (**C2**) sector-related zoning (→, →)*

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Mineralogical and geochemical evaluation of soils contaminated by arsenic-rich coal fly ash

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A coal-burning power station the Elektrarne Novaky (ENO) produces large volumes of coal combustion by-products (fly ash, bottom ash). These products are disposed in landfills. In 1965, a dam failure of an ash impoundment in Zemianske Kostoľany released approximately 3 million tons of As-rich fly ash and contaminated 20 000 ha of agricultural land. The ashes were covered by soils coming from different sites of Slovakia. Fly ash represents possible source of potentially toxic elements, because meteoric water or groundwater may interact with the ash materials in the soils and produce leachates that contain elevated levels of trace elements, in our case, arsenic. The leaching characteristics of fly ash are controlled by factors such as its chemical composition, mineralogy and morphology (Singh, 2005). The main goal of this work is assessment of geochemical characteristic of the fresh ash waste from impoundment and the soil-ash mixtures from 1965. In this study, we realised two single-step extraction techniques, distilled water and 1M NH_4NO_3-solution. Extraction with distilled water (Mackových et al., 2003) was used to determine the potential mobility of arsenic and amounts of extracted arsenic ranged from 0.065 to 1.439 $mg.l^{-1}$ (3,25-71.95 $mg.kg^{-1}$). Extraction with 1M NH_4NO_3-solution (Hall et al., 1998) was used to evaluate the bioavailability of arsenic for plants and amounts of released arsenic vary between 0.023-17.75 $mg.l^{-1}$ (0.05-44.4 $mg.kg^{-1}$). In our work we also studied chemical and mineralogical composition of fresh fly ash and soil-ash mixtures. Major ash-forming elements in mineral phases of fresh fly ash are commonly O, Si, Al and Fe. The results of WDS analysis show that SiO_2, Al_2O_3, Fe_2O_3, CaO have the greatest abundance. X-ray diffraction analysis (XRD) confirmed the present of minerals such as mainly quartz, cristobalit, aluminosilicates such as mullite, and iron oxides (hematite, magnetite, maghemite, rutile), graphite and amorphous glasses. Arsenic occurs in relative low concentrations (to about 0.13 wt. %). The soil–ash mixtures shows As concentrations to about 0.14 wt. % and the same mineralogical composition as fresh fly ash in different quantities.

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Preliminary results of geochemical investigation of tailing impoundment Markušovce, Slovakia

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Tailing impoundment is an area used for permanent or temporary deposition of mainly hydraulically consigned mud/sediment (waste). Consigned sulphide minerals in tailing impoundments react with atmospheric oxygen in oxidation processes and could produce water with low pH (AMD) and increase the mobility of potential toxic elements (metals, metalloid and sulphates). The studied impoundment contains treatment products and is classified as barite deposit, where barite is nowadays also exploited. The content of metals and elements in impoundment depends generally on the mineralogy of extracted ore and on the wall rock. Ore minerals are represented mostly by sulphides and sulphosalts like tetrahedrite (schwazit), chalcopyrite, pyrite, rare cinnabarite. The non-metallic minerals are represented mostly by barite, quartz and fuchsite (Grecula et al., 1995). The samples were collected from a drill hole (RU-1) with total depth of 37.5 m to the bedrock**.** The aim of this work was to determine the potential leachability (mobility, bioavailability) of toxic elements, according to EN 12457 (2002) and Kubová et al. (2008), occurring in impoundment in relative high concentrations. Therefore, we also determined the basic qualitative composition and physical-chemical properties (pH, Eh and EC) of tailings. We also determined the Neutralization Potential of tailing material (Sobek et al., 1978). Chemical composition of tailing solids was determined by standard analytical methods (AAS, ICP-AES). Values of Eh showed vertical differentiation of redox conditions in the body of impoundment. Average pH values of impoundment material measured in distilled water and in 1M KCl were 8.84 and 9.32, respectively. Chemical composition of impoundment material is represented mostly by SiO_2 (30.7 %), Fe_2O_3 (28.6 %), Al_2O_3 (5.3 %), Ba (6.34 %), S_{tot} (1.7 %), S_{sulf} (0.2 %), Cu (624.3 $mg.kg^{-1}$), Sb (114.9 $mg.kg^{-1}$), As (48.3 $mg.kg^{-1}$). The results from leaching procedures did not show significant amounts of extracted toxic elements that have been leached from impoundment material.

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The role of Y^{3+} and REE in the crystal structures of the zippeite group minerals

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Uranyl sulphate minerals of the zippeite group are important weathering products resulting from the alteration of primary uranium mineralization. Crystal structures of synthetic zippeite-like minerals have been described by Burns et al. (2003) and of the natural members by Brugger et al. (2003, 2006). Trivalent cations have not been expected to be entering the crystal structures of zippeite group phases up to date. Sejkoraite-(Y) is a new member of the zippeite group (Plášil et al. 2011), where Y is the dominant cation. According to single-crystal X-ray diffraction, sejkoraite-(Y) is triclinic, of the space group *P*-1. The structural formula obtained from the refinement is $(Y_{1.98}Dy_{0.24})_{\sum 2.22}H^{+}_{0.34}[(UO_2)_8O_7OH(SO_4)_4](H_2O)_{26}$, Z = 2; Y and Dy occupy three symmetrically independent sites, exhibiting a site-occupancy disorder. An electron-microprobe study revealed a similar chemical composition, $(Y_{1.49}Dy_{0.17}Gd_{0.11}Er_{0.07}Yb_{0.05}Sm_{0.02})_{\sum 1.90}H^{+}_{0.54}[(UO_2)_{8.19}O_7OH(SO_4)_{3.81}](H_2O)_{26}$ (mean of 8 analyses, based on U + S = 12 *apfu*). The chondrite-normalized REE pattern (after Taylor & McLennan 1985) shows enrichment in MREE and depletion in LREE and HREE. Cationic site strongly prefers ions with radius close to 1.02 Å (as for Y, Dy, Gd are similar). Two other zippeite-like phases containing Y were identified from Jáchymov. An orange crystalline aggregates were found to be Ca^{2+} dominating, while the green crystalline aggregates were found to be Cu^{2+} dominating. Ionic radius for $^{[8]}Ca^{2+}$ cation is 1.28 Å, oppositely to radius of 1.02 Å for $^{[8]}Y^{3}$, and a significantly smaller radius for $^{[6]}Cu^{2+}$, 0.73 Å. Both phases may represents a structures related to pseudojohannite and/or rabejacite.

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Petrographic characteristics and electron microprobe investigations on major lithotypes in the Gerarup exploration project, Southern Namibia

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The Gerarup exploration project is situated in the Rosh Pinah Formation (Gariep Belt), which is widely known for the occurrence of stratabound Pb-Zn deposits. In order to understand the metamorphic history of the ore-bearing volcanosedimentary lithologies of the Rosh Pinah Formation at the Gerarup exploration project (15 km N of Rosh Pinah), a careful petrological and mineral chemical study of common rock types, including two different mica schists and one metapsammite has been carried out.

The amphibole-bearing micaschist is characterised by green amphiboles crosscutting the foliation defined by biotite and chlorite. The lithotype contains zoned garnet crystals, which overgrew the main foliation. Amphiboles are ferro-hornblende or ferro-edenite. The biotite-muscovite-bearing micaschist consists of rotated biotite and garnet porhyroblasts within a matrix of foliated muscovite and opaque minerals (mostly ilmenite and titanite). Garnet is partially chloritised or replaced by biotite. The metapsammite forms the in Bouma Cycles and is predominantly composed of angular quartz and microcline grains. Minor types of metapsammites are biotite- and garnet-rich without visible foliation.

All analysed garnets representing different lithotypes show similar chemical evolution with a rimward decrease in spessartine, an increase in almandine and no zoning of grossular and pyrope. The garnet chemistry suggests a prograde metamorphic evolution with slightly increasing temperatures and high pressures for all three samples. The schists have been affected by upper greenschist-facies metamorphism and strong polyphase deformation. The first stage of the Gariepian orogeny is characterised by biotite and garnet formed at c. 545 Ma. During the late-tectonic stage, amphiboles grow at c. 650 °C and 6.5 kbar (after Zenk & Schulz 2004) and crosscut the main foliation. Chlorites indicate the last stage of metamorphism with a range of crystallisation temperature of 260 - 340 °C (after Cathelineau 1988, modified by Xie et al. 1997). The metapsammite was also affected by upper greenschist-facies metamorphism, while biotite, garnet and muscovite crystallised during the late stage of prograde metamorphism.

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High potassium intrusive rocks of the Ryabinovy stock, South Yakutiya and associated Au-Cu porphyry style mineralization

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The Ryabinovy alkali-syenite stock located in the northwest part of the Elkon Horst in the Central Aldan Shield (South Yakutia) is a large intrusive body of 7 x 6 km intruding granitic gneisses and gneisses of Archean-Proterozoic age. At the present-day surface the stock shape is an irregular ellipse whose major axis is oriented towards the northeast. From geophysical data, the stock has a lopolith shape with contacts dipping towards its center. Of lesser abundance, the Ryabinovy stock has a wide variety of intrusive and hypabyssal rocks, as well as brecciated, hydrothermally altered and mineralized rocks. The Ryabinovy Au-Cu porphyry deposit characterized by vein-disseminated character of ore mineralization is confined to the northeast endocontact part of the stock.

The 74 samples were collected during the fieldwork. Determination of trace and major elements in these samples was carried out using emission spectrophotometry, AA, ICP MS, and XRF analyses. Microprobe investigations were undertaken on 15 PTS for identification of rock-forming minerals and determination of their chemical composition. Isotopic geochronological studies of 12 samples from the Ryabinovy stock were carried out at theVSEGEI Lab using local U-Pb isotopic (SHRIMP) dating of accessory zircons.

Main study results based on modern petrographic, mineralogical, geochemical, and geochronological methods study are as follows:

(1) Identification of the magmatic rocks of the Ryabinovy stock in South Yakutiya shows that intrusive rocks of the Aldan Suite prevailing in the Ryabinovy stock structure belong to aegirine-augite alkali-feldspathic syenites, syenite-porphyries, and nordmakites. They are characterized by pronounced high potassium alkalinity ($K_2O/Na_2O > 2$-5).

(2) Rocks of the Aldan intrusive alkali-syenite suite and Tobuk hypabyssal suite of lamprophyres, as well as their hydrothermally altered and mineralized rocks from the Ryabinovy Au-Cu-porphyry deposit distinguished in the Ryabinovy stock are very close to each other after the geochemical specialization type shown by super-clarke accumulation of the same spectrum of elements (Au, Ag, Cu, Pb, W, Mo, Ba, and Sr) in rocks. Ore formation in the deposit is characterized by a high enrichment of potassium (up to 12-15 %) and multiple loss of sodium (up to 0.2-0.7%). That is, the high potassium character of alkalic specialization of the stock rocks complies well with high potassium specialization of microcline-sericite-carbonate alteration accompanying Au-Cu-Mo porphyry mineralization in the Ryabinovy deposit.

(3) Geochronological dating of rocks of the Aldan and Tobuk Suites forming the Ryabinovy stock was carried out using local U-Pb (SHRIMP) isotopic study of accessory zircons. The results show that most rocks of the Ryabinovy stock were formed in the interval of 143.3-125.0 Ma.

Fluid inclusion study of quartz veins within Krivoy Rog iron ore, Ukraine

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The Krivoy Rog iron deposit, situated in eastern Ukraine, belongs to the metamorphic type, emphasizing importance of metamorphism in its evolution. Different grades of metamorphism within rocks of the Krivoy Rog basin indicate various metamorphic conditions of iron ore formation. This paper presents preliminary study of fluid inclusions determining the compositions, densities and salinity of fluids, present after peak metamorphism conditions. Research includes quartz veins crosscutting low-grade iron ore, collected from the Skelevatske open pit.

During metamorphic stage, sediments of the Krivoy Rog basin were transformed into iron ore rock. Late stage metamorphic fluids were responsible for mass transfer migration in these rocks. Quartz, forming bands in iron ore, was mobilized and transported by fluids to reprecipitate in veins and fractures. The compositions of fluid inclusions preserved in quartz veins represent fluids formed during the metamorphic processes.

Observed fluid inclusions can be grouped into four types: primary one-phase aqueous, secondary one-phase CO_2, secondary two-phase and three-phase (CO_2-H_2O) and secondary three phase (CO_2-H_2O-nahcolite). Small in size, primary fluid inclusions are formed in trails, parallel to the quartz vein wall and may represent crystal growth surfaces. Irregularly shaped, one-phase, liquid CO_2 inclusions often coexist with secondary CO_2-H_2O inclusions composed of liquid aqueous phase, liquid and vapour CO_2 phases. Secondary three-phase inclusions are distributed randomly among two-phase inclusion type. They consist of solid phase, aqueous solution and liquid CO_2. The solid phase forms elongated crystals within inclusion or crosscuts the inclusion wall. Raman spectroscopy revealed that it is nahcolite (peaks at: 1046 cm^{-1}, 685 cm^{-1}, 659 cm^{-1}), plausibly accidently trapped during the inclusion formation. Studied inclusions are approximated by H_2O-CO_2-NaCl system. Raman spectroscopy confirmed occurrence of CO_2 and H_2O. Salts were not detected but decreased clathrate melting temperatures indicate the presence of salt in the aqueous solution. Properties of fluids trapped in inclusions were calculated using computer packages FLUIDS (Bakker, 2003). Densities of CO_2, fluctuating in the interval: 0,89-1.04 g/cm^3, were determined from microthermometry data and from Raman spectroscopy, based on the splitting of the Fermi diad of CO_2 (Fall et al., 2011). Salinities of aqueous solution varying between 2.5 and 7.5 mass% were predicted based on clathrate melting temperatures. Isochores plotted for obtained microthermometry data constrain the probable fluid trapping conditions. The fluids are predicted to be driven through rocks during metamorphic events in conditions of greenschist and amphibolite facies.

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Crystal chemistry and structure refinement of pyralspite garnets from Shavaryn Caram deposit in Mongolia and "Bohemian garnets"

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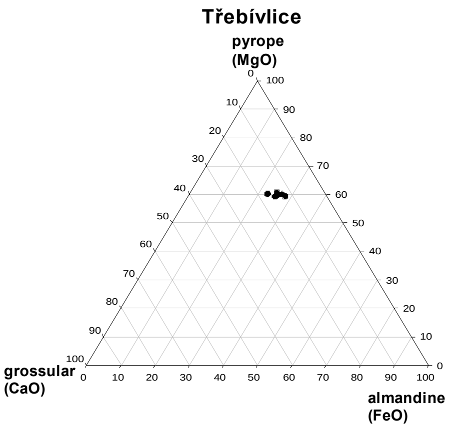
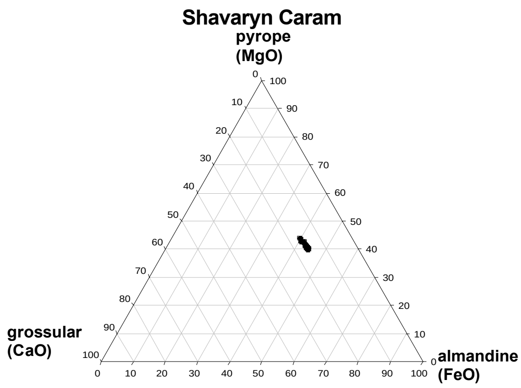
A garnet of the pyralspite group from the classical locality of Bohemian garnets Třebívlice in the Northern Bohemia (Czech Republic, 50° 45´ N, 13° 89´ E) and one from Shavaryn Tsaram deposit (Mongolia, 48° 12´ N, 100° E) were analysed using an electron microprobe (Cameca SX 100, Institute of Geology, AS CR, both Prague, Czech Republic), Mössbauer spectroscopy (Wissel spectrometer, transmission setting, NaI/Tl detector, Joint Laboratory of the Czech Academy of Sciences and Faculty of Science, Charles University, Prague) and an X-ray powder diffraction (diffractometer Bruker, National Museum, Prague, Czech Republic) with the aim to compare the chemical composition and crystal structures of these sample sets.
On the basis of the data obtained following empirical formulas were calculated:

Fig. 1. (A) *Třebívlice garnet:* $(Mg_{2,11}Fe^{2+}_{0,51}Ca_{0,36}Mn_{0,03})_{\Sigma 3,01}(Al_{1,77}Ti_{0,03}Cr_{0,15})_{\Sigma 1,95}Si_{3,03}O_{12}$;
(B) *Shavaryn Caram garrnet:* $(Mg_{1,59}Fe^{2+}_{0,94}Ca_{0,43}Mn_{0,02})_{\Sigma 2,98}(Al_{1,96}Ti_{0,03})_{\Sigma 1,99}Si_{3,0}1O_{12}$

Fig. 1. (A)



(B)



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Polymetallic veins in the western parts of the Wiborg Rapakivi Batholith, southeastern Finland

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The ore potential of anorogenic rapakivi granites has previously been investigated in detail with respect to Sn and Zn resources in southern Finland (Haapala, 1995). Recent studies have also revealed the potential for other metals and several new exploration targets have been made (Cook et al., 2011). The by far most important of these are located in the 1.64 Ga old Wiborg Batholith, where three ore types have been recognized: compact In-bearing magnetite-sphalerite ore (Pahasaari and Getmossmalmen), Zn-Cu-Pb-Ag-In-bearing greisen veins (Jungfrubergen) and polymetallic quartz veins (Sarvlaxviken, west of the town of Lovisa). This study concentrates on the latter.

In 2008-2009, six polymetallic quartz veins were discovered in coarse-grained wiborgitic rapakivi granite, immediately adjacent to a medium-grained km-sized rapakivi stock east of the Sarvlaxviken bay (part of Gulf of Finland). Each vein has a characteristic geochemical composition and mineral assemblage but they still can be divided into four groups: Korsvik, Högberget, Korsvikberget, and Virbäcken. The *Korsvik* group is enriched in Cu, In, As and Bi; locally Sn, Mn and W. The In contents of these veins are very high, up to 1.490 ppm, and roquesite ($CuInS_2$) is the main carrier. Chalcopyrite, bornite, stannoidite, arsenopyrite, cassiterite, and wolframite are also abundant. The specific geochemical signature in the Korsvik group is critical for the formation of several mineral phases; high In/Zn ratios are necessary for the formation of roquesite while high Sn contents control the formation of stannoidite on the expense of bornite. The *Högberget* group is enriched in Cu, In, As, Sn, Bi, Be, W, Zn, Pb, Cd, Mn and Ga. It is dominated by arsenopyrite with sphalerite, wolframite, chalcopyrite and cassiterite as accessories. The *Korsvikberget* group is strongly enriched in As (up to 17.3%) with lesser amounts of Sn, Bi and In. Arsenopyrite predominate (99%) with a few grains of pyrite, bornite, sphalerite, and ilmenite. The *Virbäcken* group is Cu, In, Ag, As, Bi, Be, W–rich, and characterized by chalcopyrite with accessory arsenopyrite, sphalerite, cassiterite, Bi-minerals (native bismuth, bismuthinite and emplectite) and Ag-minerals (e.g. ag-bearing cosalite).

In conclusion, all polymetallic quartz veins east of Sarvlaxviken are enriched in Cu, As and In, locally also Sn, W, Bi, Be, Pb, Cd, Mn, Ga, Zn, and Ag. All veins appear to have formed during late stage of igneous activity. The distinct geochemical compositions and mineral assemblages for each vein group suggest different conditions of formation.

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Origin of wolframite mineralization at Jeřmanice, central Europe: evidence from mineral chemistry, fluid inclusions, oxygen stable isotopes and Re-Os geochemistry

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Tungsten deposits are frequently spatially associated with intrusions of granitic plutons and subsequent hydrothermal activity. Occurrences of peripheral wolframite vein mineralization can provide important insights into fluid flow paths and ore-forming mechanisms in the vaning stages of magmatic activity. In this study we investigate distal wolframite mineralization hosted in quartz veins cross-cutting phyllites. We integrate petrographic observations, mineral and whole-rock chemistry, fluid inclusion measurements, oxygen stable isotope analyses and Re-Os geochemisty in order to estimate the pressure-temperature conditions of the ore-forming process and intensive variables responsible for wolframite crystallization.

The studied lokality (Jeřmanice, 50°41´59.961´´ N, 15°5´52.603´´ E) is located in the Saxothuringian Zone of the Bohemian Massif, Czech Republic in the exocontact of the Krkonoše-Jizera pluton. The studied mineralization is hosted by lower Paleozoic green-schist facies chlorite-sericite phyllites that are discordantly crosscut by series of quartz veins (from a few to 25 cm thick and 50-200 m long). Studied quartz-tourmaline and quartz-wolframite veins are associated with minor scheelite, cassiterite, bismuth, W- rich rutile, ilmenite and stolzite. This mineralization is accompanied by strong tourmalinization in the host rocks. The fluid inclusions trapped early aqueous-carbonic fluids that homogenize at 320-350 °C and 40-70 MPa. These values are slightly higner in comparism with the oxygen isotopic equilibrium between quartz-wolframite pair (240-280°C calculated according to Zhang et al. 1994). Absolute values of □$^{18}O_{SMOW}$, 11.1-11.6 ‰ for quartz and 9.3 ‰ for tourmaline, indicate inheritance of oxygen from the host phyllites during dissolution-precipitation reactions. The recalculated □^{18}O values of the parental fluid indicate modified magmatic or metamorphic origin. The Re-Os isotopic system showed quite unusual evolution. Their contents Re: 0.15-0.5 ppb and Os:18-54 ppt, respectively is coupled with strongly subchondritic $^{187}Os/^{188}Os$ between 0.1040 and 0.1054. These results may suggest unique behavior of wolframite with respect to Re-Os isotopic system. While the Os contents are similar to terrestrial basalts (e.g., MORB etc.), it shows much lower Re contents and $^{187}Os/^{188}Os$ similar to Martian meteorites (SNC). Therefore, it is possible that wolframites have a potential to retain primary, frozen Re-Os composition reflecting Re-Os composition of the primordial Earth's mantle.

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Characteristics of advanced argillic alteration at Biely Vrch and Kalinka localities, Javorie stratovolcano, Slovakia

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Advanced argillic (AA) alteration represents the upper most and usually the latest alteration style in porphyry-type deposits. The alteration originates by condensation of magmatic vapours enriched in acid-forming components (mostly SO_2). It usually overprints previous alteration styles, especially potassic and intermediate argillic zones. Locally it also forms hydrothermal explosive breccias. This alteration style was studied in detail at two localities in the Neogene Javorie stratovolcano: recently discovered Au-porphyry deposits at Biely Vrch and the abandoned sulphur mine in Kalinka.

The AA alteration zone at the Biely Vrch deposit is characterized by depletion of major elements Ca, Na, Mg, K, and Fe. The most intensely altered zones are also depleted in Al. In these zones only vuggy silica was preserved. Increased contents of S and P have been identified in close proximity of these zones, which is confirmed by the presence of sulphate-phosphate mineralization. The AA mineral assemblage at Biely Vrch includes kaolinite, quartz, pyrophylite, alunite, rutile, and less quantities of andalusite, dumortierite, pyrite, topaz, augelite and phosphate-sulphate mineral assemblage (REE-bearing woodhouseite to crandallite, REE-bearing "Ba–svanbergite", alunite and natroalunite). Koděra et al. (2010) also reported millosevichite and dickite in the AA zones.

The AA alteration at Kalinka is represented by quartz, kaolinite, pyrophylite, topaz, pyrite, rutile, Fe-Ti oxides, hauerite and secondary gypsum. In contrast to Biely Vrch, native sulphur is abundant, but the presence of alunite is less common. Native sulphur occurs in fragments of argillized cherts in hydrothermal-explosive breccia pipes. Some of the studied samples also contained minerals of the tourmaline group (schorl, foitite, magnesiofoitite). Tourmalines are mostly associated with quartz, locally with sericite, diabanite, apatite and are interpreted to represent an earlier stage of high-temperature alteration.

At the Biely vrch deposit, the AA alteration is recognised as the latest type of alteration, probably related to a younger post-mineralisation intrusion in depth. A similar scenario is also assumed for this type of alteration at Kalinka, while the presence of native sulphur is probably a result of precipitation in a shallower level.

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Tsagaan Tsakhir gold deposit: geology and mineralization, Mongolia

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Tsagaan Tsakhir gold deposit is located in the south-eastern part of the Bayankhongor a metallogenic belt in west-central Mongolia. The one district consists of Proterozoic tonalitic gneisses and marble-bearing schists. Cambrian granitic, small dioritic stocks and Permian lamprophyre dike. Wall rock alteration is weakly developed as silicification, sericitization, albitization, chloritization, and pyritization. Gold mineralization in the deposit is accompanied by quartz veins and veinlet zones hosted in migmatized schist and granite (Jargalan, Murao, 1998; Piestrzyński, Pieczonka, 2008). Three types of quartz veins are observed: metamorphic quartz veins, occurring in the Proterozoic shales, located in the western area, epithermal quartz-calcite veins, located in the Tsagaan Uul Tsakhir fault zone and mesothermal quartz veins with small amounts of sulphides containing native gold. Occurrence of 55 quartz veins was reported in this area. Thickness of the veins is variable from 10 cm to several meters. Gold content in quartz veins shows a wide range between 0.1 to 750 ppm.

In addition to native Au, other ore minerals were identified: pyrite, arsenopyrite, chalcopyrite, tennantite, galena, sphalerite, covellite, chalcocite, and secondary minerals such as malachite, anglesite and cerussite. In mesothermal quartz veins also tellurides were identified (krennerite, altait, petzite, hessite, nagyagite, volynskite and tellurobismuthite). Tellurides are observed with native Au and galena (Piestrzyński, Pieczonka 2009).

A series of gold mineralized quartz veins have been exploited by local "Ninja" artisanal miners to a maximum depth of 15 m depth using manual mining methods.

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FIELD TRIP GUIDEBOOK

PŘÍBRAM

The Příbram ore area is one of the most important regions of hydrothermal ore mineralization of the Czech Republic. Total production of metals from this area was 3800 t Ag, 518 000 t Pb, 70 000t Sb and 48 400 t U (Příbram uranium ore district). In 1875 the Vojtěch mine was the first mine of the world to reach a vertical depth of 1000m, the more than 1800 m depths of mining in the uranium ore district are among the greatest in Europe. The ore deposits of the Příbram ore area had a long history of mining of silver and base-metal ores: the beginning of mining dates back to the Middle Ages.

Fig. 1 *Rudolf mine, Bohutín – 20´s of 20th century, photo archive of P. Škácha.*

Geology of the Příbram ore area

The region of Central Bohemia (Czech Republic) belongs to the classic areas of economically significant hydrothermal mineralization (Příbram – base metals and uranium, Jílové – gold and Kutná Hora – silver and base-metal mineralization; Velfl et al., 2007). The ore deposits of the Příbram ore area are located near the boundary of the Teplá-Barrandian Unit (Upper Proterozoic, Cambrian) and the Central Bohemian Pluton. In this area, two main ore districts are distinguished on the basis of their geological positions and characteristics of hydrothermal mineralization: a silver-bearing base-metal ore district and a complex uranium-bearing ore district (Litochleb et al., 2003).

The Příbram base-metal ore district is represented by the main deposits of Březové Hory and Bohutín, accompanied by further smaller deposits and occurrences. The hydrothermal ore veins of these deposits penetrate the Upper Proterozoic slate and Cambrian sandstone and greywacke, especially along the NE-SW oriented "Clay Fault". These veins are mostly oriented in the N-S direction; shorter NW-SE striking veins also occur in the shallow zones (Bernard, 1991). The ore veins at Březové Hory deposit follow the course of basalt dykes of Early Paleozoic age. They have been mined within an area of about 10 km^2. 43 veins are known in the shallow zones, whereas there are 5-6 main veins at depth. The most significant is the Main Vojtěch vein, which is about 1 to 2 m thick; however, it is exceptionally 6 m thick or even thicker. It has a length of 3.5 km and was followed to depth to 1580 m below the surface (41 levels) by the Vojtěch and Prokop shafts. At middle depths, the monomineralic parts of this vein with Ag-bearing galena were as much as 70 cm thick. The average grade was 450 g/t of Ag, and the specific grade was 0.6 kg of silver per m^2 in the plane of the vein. In the deeper part of the deposit, the ore mineral infillings of veins contain abundant “hard ore” which consists of fine-grained quartz with disseminated pyrite, galena, sphalerite, boulangerite and Ag minerals.

The ore veins at the Bohutín deposit transect the Bohutín amphibole-biotite quartz diorite, the oldest component of the early Variscan magmatism of the Central Bohemian Pluton. Klementská vein, the most important vein of the Bohutín deposit was mined to a depth of 1350 m along a 2-km long section. The characteristic “hard ore” known from the Březové Hory deposit was not developed here, but younger antimony mineralization (stibnite, berthierite) mineralization was mined out at this deposit. The youngest uraninite-carbonate stage (uraninite, Ni-Co-Fe arsenides) and also sphalerite and silver ores are characterized by irregularly mineralized veins of the smallest deposit (Černojamské) in this ore district. More than 160 mineral species are known from the Příbram base-metal ore district. Many minerals occurred here in very well-developed forms displaying extraordinary variability of crystal shapes, types of twinning and colours (Ag minerals, calcite, barite etc.). In spite of the relative abundance of silver minerals (22 species, especially native silver, argentite, pyrargyrite, stephanite and freibergite), the most important source of this metal was the Ag-rich galena; however, other sulphide minerals like sphalerite, bournonite and boulangerite also contained high amounts of silver due to their microscopic intergrowths with Ag minerals.

The complex uranium-(base-metal) ore district at Příbram represents the largest accumulation of vein-type hydrothermal uranium ores in the Czech Republic and is comparable to world-class deposits of this type. Uranium mineralization is bound to a 1-2 km wide and almost 25-km long zone formed by a strongly tectonized zone of Upper Proterozoic rocks along the contact with granitoids of the Central Bohemian Pluton. The central part of this district, between the Lešetice and the Bytíz deposit, concentrated more than 98% of the total uranium production; 52% of the uranium ore was extracted from the richest Bytíz deposit that comprised 584 mineralized veins. The main vein structures were traced for 2.4 – 2.7 km along their extension and to a depth of 1.1 – 1.4 km under present surface. More than 210 mineral species were found there. The main economic ore consisted of uraninite together with some coffinite and U-bearing antraxolite (a bituminous substance). The lens-shaped ore bodies reached up to 0.3 m in width and were almost 20 m^2 in size. Parts of the legendary Bt4 vein in the Bytíz deposit exhibited a specific grade of 60-100 kg of uranium per m^2 in the vein plane.

The origin of mineralization

The oldest mineralization stage is related to intrusions of granitoids of the Central Bohemian Pluton. These intrusions caused intense contact metamorphism in their host rocks consisting of Barrandian Upper Proterozoic units. Bodies and layers of contact skarn with wollastonite, Ca-Mg-Fe pyroxene, amphibole and especially ugrandite group garnets (up to practically monomineralic garnet rocks) and scheelite-bearing hornfels developed close to the external contacts of granitoids (area of uranium ore district, Litochleb et al., 2005). Early Variscan (about 350 Ma) gold-bearing quartz-sulphide vein mineralization is relatively widespread in the Příbram ore area but its economic significance is minimal. The occurrences of quartz veins and veinlets with fine-grained gold, sulphides, Bi minerals (native Bi, bismuthinite, Bi sulphotellurides), sulphosalts are known in both the ore districts from the surface to the deepest levels of the mines. In the Příbram ore area, the late Variscan (270-290 Ma) vein-type base-metal and uranium mineralization is the most significant. These types were developed in both ore districts distinctly and with different intensity depending on the geological and structural conditions. The hydrothermal processes of vein formation were classified into several stages in the temperature range of 300-70°C. In the Příbram base-metal ore district, the older base-metal stage dominates. It is represented by quartz-siderite-calcite veins with galena, sphalerite, pyrite, tetrahedrite, bournonite, boulangerite, and Ag minerals etc., with occurrences of well-formed crystals of these mineral species. A younger barite-stibnite stage developed only in the Klementská vein of the Bohutín deposit. The youngest uraninite-carbonate stage (uraninite, coffinite, Ni-Co-Fe sulphides and arsenides) is knows at the Černojamské deposit (Lill mine) and only very locally at the Březové Hory (Jánská vein) and Bohutín (Severozápadní Řimbabská vein) deposits (Litochleb et al., 2000b; Škácha et al., 2009). In the Příbram uranium ore district, base-metal (siderite-quartz veins with galena and sphalerite) mineralization also occurs in the oldest siderite-sulphide stage. The predominance of calcite (with several generations) is characteristic for the superimposed stages. Abundant uraninite aggregates were formed in the calcite-uraninite stage. The origin of uraninium-bearing antraxolite was connected with the youngest calcite-sulphide stage, which is also characterized by occurrences of coffinite and montroseite, sulphides, arsenides, sulphosalts, selenides, native silver and silver minerals, zeolites and whewellite (Litochleb et al., 2002, 2004). This youngest stage is considered to be the result of remobilization from the earlier stages. The origin of monometallic accumulations (bonanzas) of extremely rich silver ores (e.g. Brod deposit, shaft No. 6 or Háje deposit, shaft No. 21) is also assumed in this youngest stage.

History of mining

In spite of the fact that mining in the Příbram base-metal ore district started already in the 13th century, almost 97% of all reserves has been exploited during the last 170 years, between 1810 and 1980. The main prosperous period of mining began here in the second half of the 18th century due to technical improvements introduced by Bergmeister (mine inspector) J. A. Alis (opening of mines by deep vertical shafts, construction of a new smelter and water reservoirs and races). In 1779, the Vojtěch mine, the first vertical shaft was opened, and four mines (Anna, Ševčiny, Marie and Prokop) followed shortly afterwards. In 1875, the Vojtěch mine was the first mine in the world to reach a depth of 1 000 m. Almost 100 years later (1966), the Prokop mine reached a maximum depth of 1597.6 m as the first mine of this depth in the former Czechoslovakia. The individual mines of the Březové Hory and Bohutín deposits were interconnected by the main 9 km long drainage gallery (completed between 1789 and 1859) and additional adits with a total length of 19 km. The Bohutín ore deposit was opened by the Rudolf, Štěpán and Řimbaba main shafts; it was mined down to a depth of 1350 m below the surface (Bambas, 1990; Tvrdý, 2003). First silver and later lead were the principal extracted metal components of the ores, with other by-products such as zinc and, to a lesser extend, antimony and gold improved the economy of mining. Mining of the Březové Hory deposit was finished in 1978 and of Bohutín deposit in 1980. Almost 22 million tons of ore with 3837 tons Ag, 517 961 tons Pb and 70 300 tons Sb have been mined during the whole period of exploitation of the district. 58 % of the total amounts of silver and at least 90% of the total amount lead which have been extracted in Czech territories have been mined from this district.

Exploration of uranium ores in the present Příbram uranium ore district started in 1947. Almost 60 economic occurrences were located within the 50-km^2 large area. The mining period started by opening the first shafts (No. 1 and 2 – Vojna) in 1948. During the first decade, the vein system was explored to a depth of 500 m from 20 new shafts.

Fig. 2 *Ševčín mine - Příbram, Březové Hory, photo P. Škácha, 2006.*

A relatively short time between the discovery of the first indicators of uranium anomalies (1947) and the beginning of extraction (1950), together with the extraordinary scale of the ore bodies, qualified the Příbram uranium ore district for competition with the most important ones in the world. Uranium mining culminated in 1975, when this ore district became the main producer of uranium ores in the former Czechoslovakia. More than 2500 carbonate veins were found and prospected within this ore district formed by a number of individual ore deposits (e.g. Kamenná, Lešetice, Brod, Háje, Bytíz). The uranium mineralization occurred in 1641 veins, base metals mineralization in 35 veins and finally monomineralic silver mineralization in 19 veins. In 1976, the final depth 1838.4 m was reached in shaft No. 16 (Háje). At that time, this was the deepest vertical ore mine in Europe. The extraction of uranium ores in the ore district was terminated in the Dubenec mine in September 1991.

Between 1992 and 1998, an underground gas reservoir with a capacity of more than 620,000 m^3 was built on the 21^{st} level (about 1000 m under surface) on shaft No. 16 (Háje). This reservoir was formed by 107 interconnected storage tunnels with a total length exceeding 45 km (Litochleb et al., 2000a). Now mining in the uranium ore district can be seen from 27 large mine dumps part of which are used as resources for production of crushed and sorted rocks. The following numbers indicate the remarkable extent of the mine works in the uranium ore district of Příbram: 23 km of shafts, 2188 km of horizontal adits and 300 km of chutes were created in an area of 57.6 km^2 over 44 years (1948–1991). The total production of 48,432 t of pure U metal represented 49% of Czechoslovak production since 1945. The parallel extraction of base metals and silver from veins produced more than 6000 t Pb, 2400 t Zn and 28 t Ag (Litochleb et al., 2003).

Mineralogical treasures of the Příbram area

In addition to the economic, historical, geological and mineralogical importance of the deposits of the Příbram ore area described above, these deposits are also world famous as sources of a large number of high-quality mineral samples, which are presented in many museums and private collections (Škácha & Plášil, 2002). The most complete collection of mineralogical samples from both ore districts is deposited in the Mining Museum of Příbram; a great many high-quality samples can also be found in the excellent mineralogical collections of the National Museum in Prague. In the Příbram base-metal ore district, silver minerals are quite abundant (Sejkora & Litochleb, 2003a). Native silver forms rich irregular and wire-like aggregates and sheets with up to 7 cm in size, often together with aggregates, pseudomorphs and crystals of argentite up to 2 cm in size. Beautiful, dark red pyrargyrite (up to 2.5 cm), columnar stephanite (up to 4 cm) and thin tabular polybasite (up to 1 cm) crystals were also locally abundant. On the other hand, red proustite (up to 2 cm) and elongated tabular pyrostilpnite crystals were very rare. Diaphorite represented the main Ag-bearing mineral of the "hard ore" and was common as microscopic grains in galena. It´s striated, up to 1 cm long columnar crystals were rare and belong among the best in the world. Similar freieslebenite crystals up to 0.5 cm in size were found in association with acicular crystals of owyheeite.

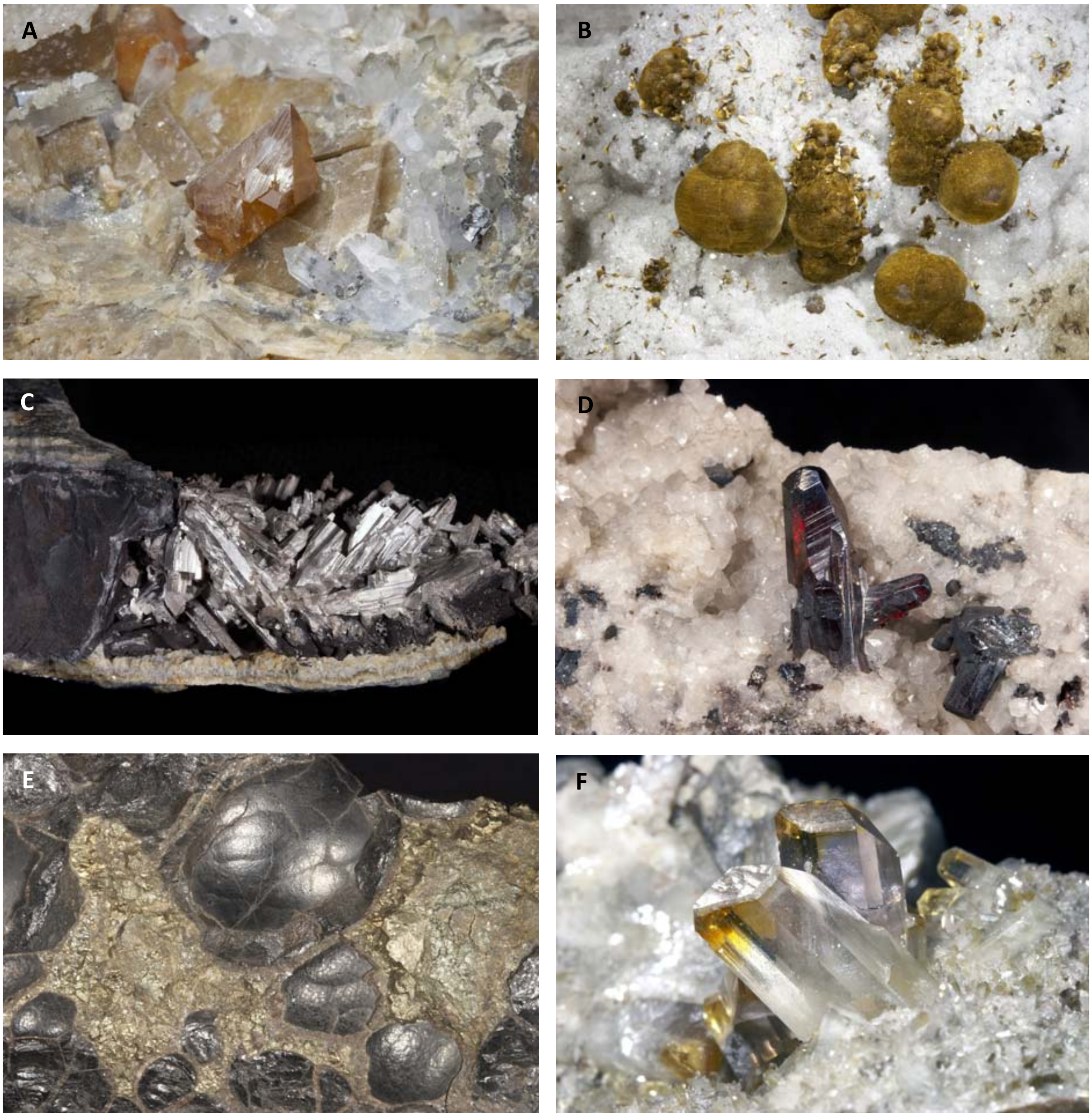

Fig. 3 A) *Scheelit - Příbram, Březové Hory ore district, Vojtěch mine (Crystal size 9 mm);* ***B)*** *Ehrenverthit (8mm in size) on dolomite - Příbram, vein Vojtěšská, 20^{th} level;* ***C)*** *Dyscrazite - Příbram, mine No. 21, 7^{th} level, vein H14F3 (photo width 8 cm);* ***D)*** *Pyrargyrite on calcite - Příbram, Březové Hory ore district, vein Vojtěch, 21^{st} level (crystal size 12*5 mm);* ***E)*** *Uraninite – Příbram, Březové Hory mining district, vein Jánská, 15^{th} level (crystal size 2 cm);* ***F)*** *Barite – Příbram, Březové Hory ore district, Ševčín mine, vein Mordýřská, 10^{th} level (crystal size 2 cm). All specimens belong to the collection of the mining museum in Příbram, photo P. Škácha.*

Fig. 4 A) *Pyromorphite – Příbram, Březové Hory mining district, Anna mine, vein Jánská, 7th level (crystal size 7mm, on limonite);* ***B)*** *Native silver - Příbram, Březové Hory ore district, vein Mariánská, 12th level (Ag 8 cm). All specimens belong to the Collection of the museum of mining in Příbram, photo P. Škácha.*

Galena is the most important ore mineral in the base metal ore. It occasionally forms up to 5-6.5 cm large simple crystals in cavities of gangue. One of the youngest generations of galena forms octahedral crystals up to 1 cm in size with strong metallic lustre (called steinmannite). Bournonite was other well-known mineral from Příbram and occurs as multiple intergrown crystals up to 5×4×2 cm in size. Ag-rich tetrahedrite usually forms only fine-grained aggregates but crystals of this mineral up to 2.5 cm have also been found. Boulangerite was by far the most abundant sulphosalt, the best samples of which were formed by rich aggregates of fibrous crystals up to 15 cm long. Quartz, siderite, calcite and barite were the main minerals of the gangue.

The calcite samples were remarkable not for their size but for the extraordinary variability of types, crystal shapes, types of twinning and colours. One of the most beautiful minerals of the Příbram base-metal ore district is undoubtedly barite, which forms at least two generations. The older barite occurs as yellow, greyish yellow, pale blue or pinkish thick tabular crystals up to 10 cm in size, often overgrown by crystalline crusts of dolomite, calcite and pyrite. The younger barite forms the smallest (usually 2-3 cm) very well-formed transparent columnar crystals with large colour variability: colourless, white, pale blue, bright yellow, pink or red. Yellow to brown lenticular siderite crystals up to 3 cm in size and a red-brown variety of goethite forming aggregates and crusts with a typical velvet surface also belong to characteristic minerals here. Very interesting minerals are also known from the oxide zone of the deposit (Sejkora & Litochleb, 2003b). The white, yellow, grey and dark coloured crystals of cerussite with size of up to 2 cm and the whitish to yellow hexagonal crystals of mimetesite up to 1 cm in size are among the most spectacular species. The most beautiful supergene mineral is the pyromorphite, which forms elongated or thick columnar crystals, usually up to 2 cm in size. Pyromorphite crystals are frequently grown to rich druses on strongly limonitized gangue. The majority of pyromophite crystals are green to remarkably bright green incolour; bright yellow or brown crystals are rare. A great many interesting mineral samples also characterize the Příbram uranium ore district (Růžička, 1986; Sejkora & Litochleb, 2003a).

The most significant finds are the native elements. Superb samples of native silver were found at several deposits (e.g. Háje, Brod). The irregular, columnar or wire-like silver aggregates in the calcite gangue weighed up to tens of kg and silver wires up to 10 cm long were also occasionally found. Pseudomorphs of native silver after dyscrasite crystals up to 7 cm in length also occurred. Stibarsen and arsenic were relatively abundant in some parts of the veins (Háje, Brod, Bytíz, Třebsko deposits), where they formed stratified hemispherical aggregates up to 15–20 cm in size. A large lens with thickness to 25 cm in a 3×3 m plane of pure native antimony was found in the calcite vein of the Bytíz deposit. It yielded pure native antimony samples with weight of up to 10 kg and rarely also trigonal crystals up to 1 cm in size. Mineralogically unique accumulation of dyscrasite crystals originated from the Háje deposit (shaft No. 21). Columnar crystals of dyscrasite 1–8 cm in length or skeletal aggregates up to 3×6 cm in size were always enclosed in aggregates of native arsenic. Another type of dyscrasite is known from the Brod deposit (shaft No. 15) where it formed granular aggregates up to 10–12 cm in size in the siderite–kalcite gangue (Kolesar, 1990; Knížek et al., 1990). Uraninite was the prevailing uranium mineral in the uranium ore. It forms black reniform (up to 20 cm in size) or spherical aggregates, veins and massive lens in older carbonate gangue. In the Kamenná, Brod and Bytíz deposits, the thickness of masive uraninite lenses reached up to 10–20 cm exceptionally 50–100 cm) and their plane had an area of up to 20 m^2. The most abundant mineral in the veins was calcite, which occurred in six generations. Large druses of calcite crystals were abundant in open spaces of veins; the plane of these cavities had an area of 20–40 m^2 (exceptionally over 100 m^2) with a thickness of up to 0.5–1.4 m. The size of individual scalenohedral calcite crystals reached 40 cm. Interesting crystals of zeolites (analcime, harmotome, stilbite, heulandite) were also found in druses of veins, in a similar way as the very rare, well-developed whewellite crystals up to 8 cm in size (Knížek & Litochleb, 2005).

Field trip itinerary – Příbram

STOP 1 Mineralogical collection of the Mining museum Příbram

The mineralogical collection consists of about 4000 samples from the region, several hundreds of which are in expositions. Minerals of the Březové Hory ore district and the uranium district predominate. We can mention silver minerals in large crystals and masses, perfect bournonite crystals, nice boulangerite aggregates, large barite and stibnite crystals and supergenne minerals especially. A small exposition of trilobites from the Jince area is also present.

STOP 2 Drkolnov Mine

Drkolnov mine was established in the first half of the 19th century in the southern part of the Březové Hory ore deposit. It reached the depth of about 500m but without any mentionable ore founds. In the middle of the 20th century this shaft served as a water source. An old reconstructed water wheel used before for pumping water from deeper levels of the shaft served for this purpose. This 12.5m large water wheel was later abandoned for a long time but several years ago it was reconstructed and made accessible to the public.

STOP 3 Water Course level (near Anna mine)

This adit was used as an upstream waterway in the 18th century and later for powering the water wheels. We can see here both upper proterozoic slates and lower cambrian greywackes and sandstones and the co called "Clay fault" - the most important fault in the Příbram area. Furthermore we can see a typical profile of the mining works in the 18th - 19th century.

STOP 4 The Vojna Memorial

In the midst of the forest 5 km south-east of Příbram at the boundary of the Lazsko, Lešetice and Zavržice village areas in the place which was famous for iron, silver and uranium ores occurrence a labour camp built by German war prisoners between 1947 and 1949 was based. It was named after the Vojna Mountain (666 m a.s.l.). Analogous camps were also in the Jáchymov and Slavkov districts close to the deposits of the strategic uranium ore.

In 1951 the Vojna Hard Labour Camp was reorganized and converted into the Vojna Reformatory Hard Labour Camp and its contemporary identification was NPT-U. Actually it was a prison. Its 'charges' were first of all '... the most dangerous offenders, dangerous especially for the state ...'. Actually they were advocates of democracy accused in framed-up lawsuits and interned for 10 and more years, most often they were guilty of treason, attempted treason, aiding to treason, espionage, an attempt to leave the republic illegally, subversive activities (especially according to the 231/1948 Act about protection of the people's democratic republic and according to the 86/1950 Act). The prisoners who served their execution of punishment were also criminals, old lags and those accused of illicit trade. A small exposition of uranium mining in Czech Republic was recently built in this areal .

STOP 5 The dump of the shaft No. 16.

The shaft No. 16 is one of the most important shafts of the uranium district. It reached the depth of more than 1800m. On the dump of this shaft we can often find nice calcite veins today. It is possible to find uraninite in aggregates. Secondary uranium minerals like schrockingerite, uranospinite and schoepite are relatively abundant.

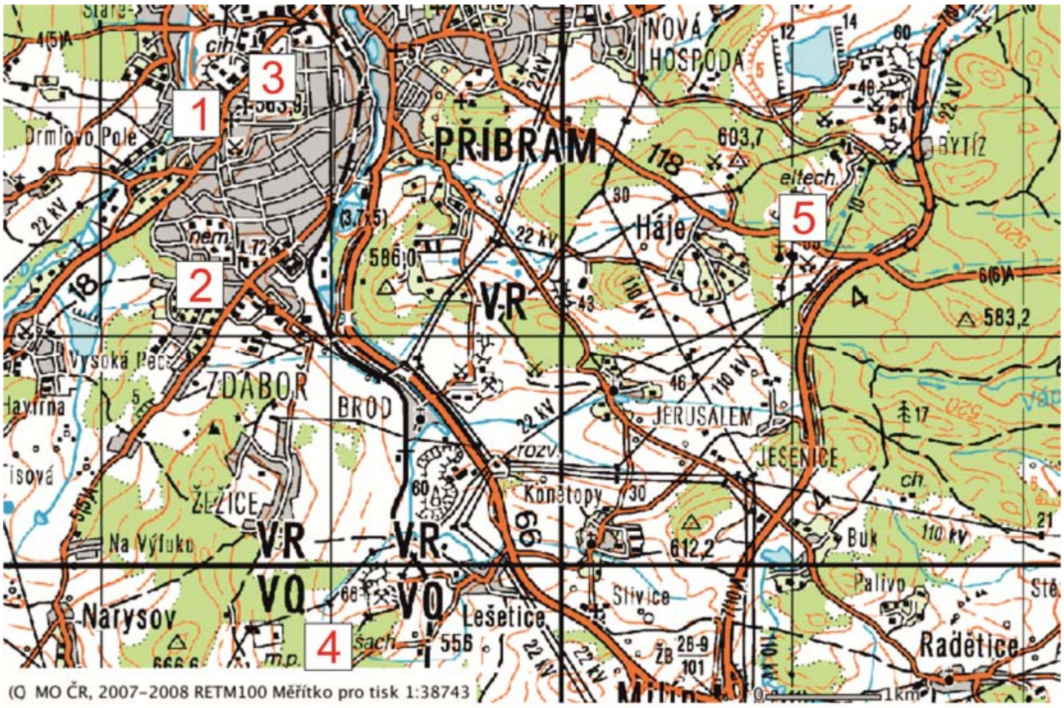

Fig. 5 *Schematic map of stops and areas of interest for the SGA field trip to Příbram - April 18, 2011.* ***1)*** *Mining museum in Příbram,* ***2)*** *Drkolnov mine,* ***3)*** *Water course level,* ***4)*** *The Vojna Memorial,* ***5)*** *The Dump of the Shaft No. 16.*

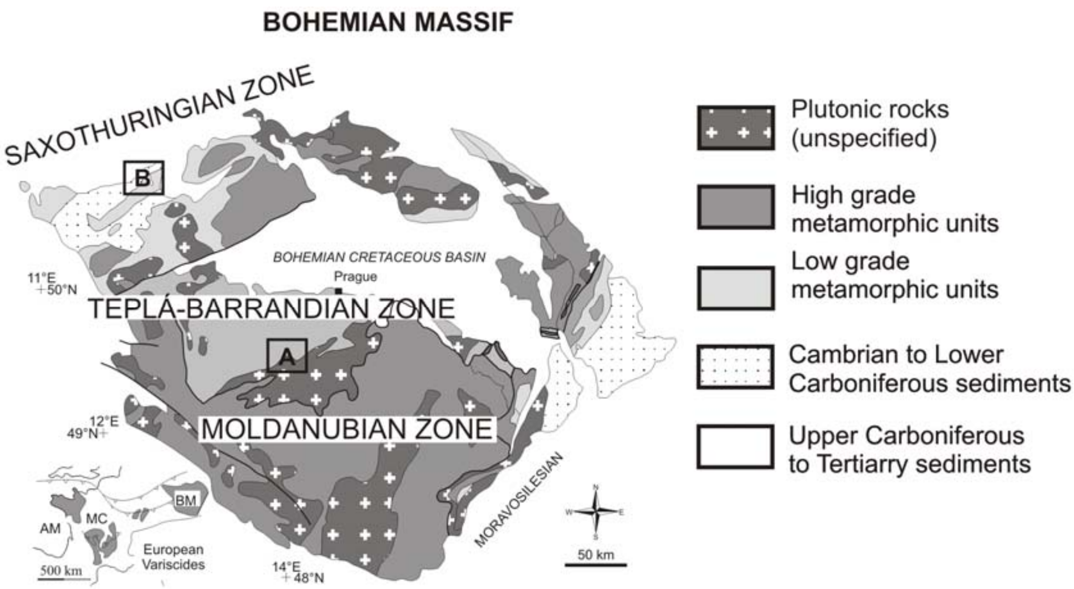

Fig. 6 *Schematic geological map of the Bohemian Massif within the European Variscides,* ***A*** *– Příbram,* ***B*** *– Jáchymov, courtesy of J. Trubač.*

Jáchymov

The ancient town of Jáchymov (St. Joachimsthal) is situated in the Krušné hory (Erzgebirge) massif, 14 km north-east from Karlovy Vary (Carlsbad). The nowadays small spa-town, with 3000 inhabitants, seems to be rather distant from the political and cultural life, but several times during its high-wrought history, starting at the beginning of the 16th century, it was the real centre of culture, knowledge and political matters o the high importance were solved there. Shorten, you are in the places where history went through, as everywhere else, but you can feel it somehow more live from the city there, than in other places.

Fig. 7 *Jáchymov (St. Joachimstahl), photo archive.*

In the beginning of the 16th century there was just a huge primeval border forest only with occasional wooden-less, free space, called "grüns" (like green meadows). In the place of one of these meadows lying on the traditional route from Annaberg to the Bohemia kingdom, the settlement named Konradsgrün was established. This ancestor of the later town Jáchymov, Konradsgrün, was situated in the area of today´s square "Na Slovanech" called formerly "The Bread Market" (Brotmarkt).

In 1437 the emperor Zikmund pawned the large border area to the chancellor – count Kašpar Šlik. First effort and trials in the term of prospecting the ores was made in 1511 in the Czech part of the Erzgebirge Mountains and one year later, two miners – Kaspar Bach from Geyer and old Oeeser from nowadays Ostrov nad Ohří (former Schlackenwerth) tried to win the adit at the foot of the Zámecký hill. This adit called Nálezná/Fundgrübner (Discovery) or frequently also Tříkrálová štola/Dreikönigerstollen (Three Kings Gallery) was suddenly abandoned due to the lack of finance. However, Štěpán Šlik – owner of the manors - hired the mine workers and established the mining company together with lords of surrounding lands.

History of the mining district

The first rich finding of the silver ore was made in the Fundgrübner´s vein and this event was followed by further silver ore in huge amount. The good news about this great finding quickly spread around and triggered arrival of new miners from neighbouring companies and mining towns. Silver rush attracted thousands of people who wanted to make a fortune and great mining and building activity related with the population explosion in the calm valley began. In 1516 there were about 400 houses in the settlement and one year later Kašpar Šlik decided to build the castle Freudenstein above the incipient town for protection and to prevent disorder among miners. The first mining strike came soon, so on 2nd August 1518 the first mining order was created – "Šlik´s mining act", having 106 articles on the basis of the example of Annaberg´s one.

Rising importance of the town brought an idea to find a name for it. On 6th January 1520 the town of Konradsgrün was honoured by the power of His Majesty Ludvík the Jagellon and named “Valley of St. Joachimi” – St. Joachimsthal on the pattern of the mining tradition in Saxony. On the heraldry of the town (Fig. 8) we can see St. Joachim and St. Anna, the parents of the St. Maria and the symbol of miners – crossed hammers. Jáchymov in the first half of 16th century can be rightfully considered the most famous silver ore deposit in the world of its time. More than 5000 people lived here and most of them worked in hundred of mines.

Fig. 8 *The Jáchymov town-heraldics.*

Geomorphologic conditions helped the quick development of mining. The richest zone of secondary cementation enrichment of the veins with abundant native silver was in the depth of 60-80m but the silver veins often reached the surface and silver was found just under the grass or in the roots of fallen trees. Such pieces of silver of the weight of up to 100 kg were called “Rasenläufer”. Georgius Agricola and Johannes Mathesius documented these findings for us recorded them in their masterpieces - “Bermannus, Sive de re metallica” (GA) and “Sarepta, oder Bergpostil” (JM). In the year 1519 Šlik started stamping valuable “thaler” (Joachimsthaler), which spread widely and were accepted not only in Bohemia but abroad as well.

Later, they were even the base of the American dollar! In the years 1520-1528 the coin production exceeded 3 million of thalers. During the first 80 years (1516-1600) around 330-350 tons of silver were mined. This yield classified Jáchymov as a world class silver producer with an average production of 6,9 tons in the years 1516-1545. The number of inhabitants increased dramatically with the maximum of 18200 in the year 1534. With this number Jáchymov became the second most populated city after Prague as capital city, not only in Bohemia but in Saxony as well. In the year 1533, when mining reached its peak, 134 silver veins were discovered, 914 mines were in operation with more than 9000 workers. In this period when Jáchymov won the world fame, it was a centre of European culture. To the most famous and known belong doctor and scientist Georgius Agricola, lutheranian pastor Johaness Mathesius and musician Hermann Nickel. From these times almost all important landmarks originate, as originally hospital church of St. Anna (Fig. 8), decanal church of St. Joachimi, Schlick’s and later the royal mint, Freudenstein castle and many patrician houses in the town. After 1545 a decrease of mining caused by exhaustion of surface part of the deposit and thus higher costs as well as tight political situation in the state started. Cheap silver from South America accelerated the fall of Jáchymov mining at the end of the 16th century. In 1621 just 2000 inhabitants remained in the town. Many natural disasters, as fires and droughts, diseases, such as plague, and war front went through the city. That helped to quick the failure of the former town called "The pearl of Erzgebirge".

Fig. 9 *Jáchymov cemetery with a church of All Saints, the oldest building in the town, photo J. Plášil.*

After silver ores, the interest was focused on further metals, which come along the silver at the veins. It was going namely about Co and As in the firstly. Thanks to financial support at the beginning of the 18th century certain regeneration of mining occurred and on 13th January 1716 first mining apprentice training centre in the world was established. Despite the silver price increase in the period of 1745-1754, production of silver was only 296 kg. Cobalt ore mining developed and in the second half of 18th century Jáchymov starts its second boom. Cobalt and less the arsenic were used for colour manufacturing. Since 1755 silver mining started increasing again. The main source came from the „Svornost"/„Einigkeit" (Concordia) guilt belonging to the municipal mining with the vertical pit Svornost 292 m deep (Fig. 10) and „Vysoká jedle" guilt/„Hohe Tanne zeche" (Tall Fir) with the inclination of 115m in the Sv. Kříže (St. Cross) shaft.

Successful development was stopped by the war, famine and plague. Big fire in 1782 meant total destruction for the town. At the beginning of the 19th century Jáchymov mines reached the depth of 665m which made them ones of the deepest mines in the world. However, there was a problem of flooding in the lower parts of the mines. Operation costs increased and the state authority recommended reducing mining activity. The history of mines seemed to be closed. At that time strange black ore uraninite started to be interesting. It contains an element discovered in 1789 by Martin Klaproth – uranium. The ore was known for hundred of years among miners under the name "Pechblende" (Bad luck ore) or "smolinec" (in Czech). When this ore occurred at the vein, usually silver ores diminished, that is why the name bad-luck for that ore, given from old miners in 16th

century. Uraninite began to be mined due to increasing demand of uranium colours (Fig. 11) used for glass and ceramics paintings in K. K. Uranfabrik in St. Joachimstahl. This luck save the Jáchymov mines again from a complete fall. Then the discovery of the natural radioactivity and later the radioactive elements radium and polonium, saved Jáchymov again after uranium colours began to be obsolete. In 1898 the well-know letter from French professor Pierre Curie (1859-1906) and his wife Marie Sklodowská-Curie (1867-1934) arrived to Jáchymov mining direction. They ask them for 10000 kg leached waste from production of uranium colours. They were heard of and thus, new radioactive elements radium and polonium were separated from this waste material. The real "Radium rush" started in Jáchymov after this. Excursions from all over the world arrived in Jáchymov and the town became a famous mining centre again. Until the WWI Jáchymov plant for the radium preparations had the world monopoly for radium production with the output of 1-2 grams of radium per year.

Fig. 10 *Svornost pit in the night town above the decanal church of St. Joachimi, photo Psycho.*

Shortly after the beginning of uraninite mining in 1864 by deepening of the Svornost shaft under the 12th level an inrush of water from today's spa spring Curie occurred and started flooding the levels up to the hereditary drainage gallery Daniel. This spring was later one of the base for the first radon spa in the world (1906). After 1918 the Czechoslovak state took over all local mines and started their general reconstruction. Between 1926 and 1932, 200 tons of uraninite ore were mined a year and 290 people were employed in the mines.

Uranium mining continued during the WWII as well under the operation of German imperial direction. After the nuclear bombing of the Japan the tension in the world between the two political systems represented by the USA and the Soviet Union increased, the iron curtain fell down, and the Cold War began with the threat of a nuclear conflict. That was the reason for quick Russian occupation of Jáchymov district by the Soviet army as early as in May 1945. Jáchymov was highly important for the Soviet strategy. Such a sarcastic names for the things that had to follow. The Soviet Union insisted on quick hand-over of the mines as thank for liberation. So in November 1945 a disadvantageous international contract about exploration, mining and delivery of radioactive raw materials was signed by the delegates of Czechoslovak (H. Ripka) and Soviet governments (V. Molotov).

Fig. 11 *Yellowish-green uranyl-nitrat, photo archive.*

From 2nd July 1945 after overcoming the initial obstacles, exploration for the uranium ore was performed in Jáchymov mines with a total of 122 employees. In 1955 in the top period of mining the state company employed 46 351 permanent staff out of which 9 214 prisoners arrested for namely political crimes, mostly in mounted/fake trials. Because of lack of workforce after the war, when at least all German inhabitants were driven out (excluding professional miners in the first years) a lot of German war prisoners were employed here, too, with a total of around 12 000 persons, but at least all of them were released in early 50ties and replaced by political prisoners. During the operation of the national enterprise “Jáchymov mines” approximately 65 000 prisoners were used for hard manual work in the mines. In 1950´s work labour camps according to the model of Soviet “gulag” arose here. Living conditions in the labour camps were absolutely terrible, near by the border for survival.

The main aim was to mine as much ore as possible in the shortest time and deliver it to the Soviet Union. 25 base pits with 162 levels were built. The cross adits with 212.7 km and 472 km of headings were dug, more than 400 veins were mined with production of 7199 t of uranium. By 1962 most of the veins and districts were exploited yet and the mines were being prepared for closing. On 1st April 1964 the last pit “Jeroným” in Abertamy was closed and the mine Svornost was handed to the Czechoslovak State Spa for exploitation of radioactive water for bathing purposes. Not only huge dumps, engine rooms, sorting plants and concrete foundations of mine towers are the only witnesses of this intensive mining now, but the last period of the history totally changed the mind and character of the people living there. The real mining activity has definitely passed in Jáchymov now (Horák, 2000b).

Geological characterisation of the deposit

Jáchymov ore deposit lies between Horní Suchá, Popov, Mariánská and Vršek with the area of approx. 35 km². It is hard to define the boundary of the deposit because other districts are connected with the deposit in many parts (Boží dar district in the north, Abertamy district in the north-west), more useful is therefore called the whole area as Jáchymov ore district. The less broad, let’s say most important part of Jáchymov ore district may be outlined by the important tectonics, faults, including these: Central fault zone in the west (direction NW-SE), Plavno fault in the east (direction NW-SE), Velká jílová rozsedlina (Great Clay Rift) in the north (direction E-W) and Krušnohorský (Erzgebirge) fault (direction NE-SW).

The area of Jáchymov is built mainly by the metamorphic rocks. The central part of the district is formed from the mica schist series of the crystalline complex, so called Jáchymov mica schist series, which is connected to the Klínovec mica schist series in the east and continues into the post-metamorphic granitoids of the Karlovy Vary granite massive in the western part of the district in the area of the Central fault. The crystalline complex includes mainly mica schist rocks and phyllites. The intensity of metamorphism weakens towards the north. In the south part mica schist and gneiss prevail, while in the northern part phyllites do. The mica schist complex is penetrated by many vein bodies and tiny basalt conduits. Magmatic rocks are represented by the Karlovy Vary granite massive in the west. So called “Rudohorský” type of granite, lies underneath the whole Jáchymov district in the depth of 200-800m. The tectonic structure of Jáchymov is formed by a huge anticline fold of the E-W direction (Klínovec fold), which passes through the entire district and sinks gradually to the west. A lot of significant fault zones cut the area in the directions NW-SE and E-W into individual blocks. These faults were mineralization channels for ore-bearing solutions during the repeated mineralization periods. The ore veins detach directly from main fault lines as pennate dislocations or form vein accompaniments. Several hundreds veins and vein accompaniments were discovered here. These were since the very beginning separated into two groups (Fig 12).

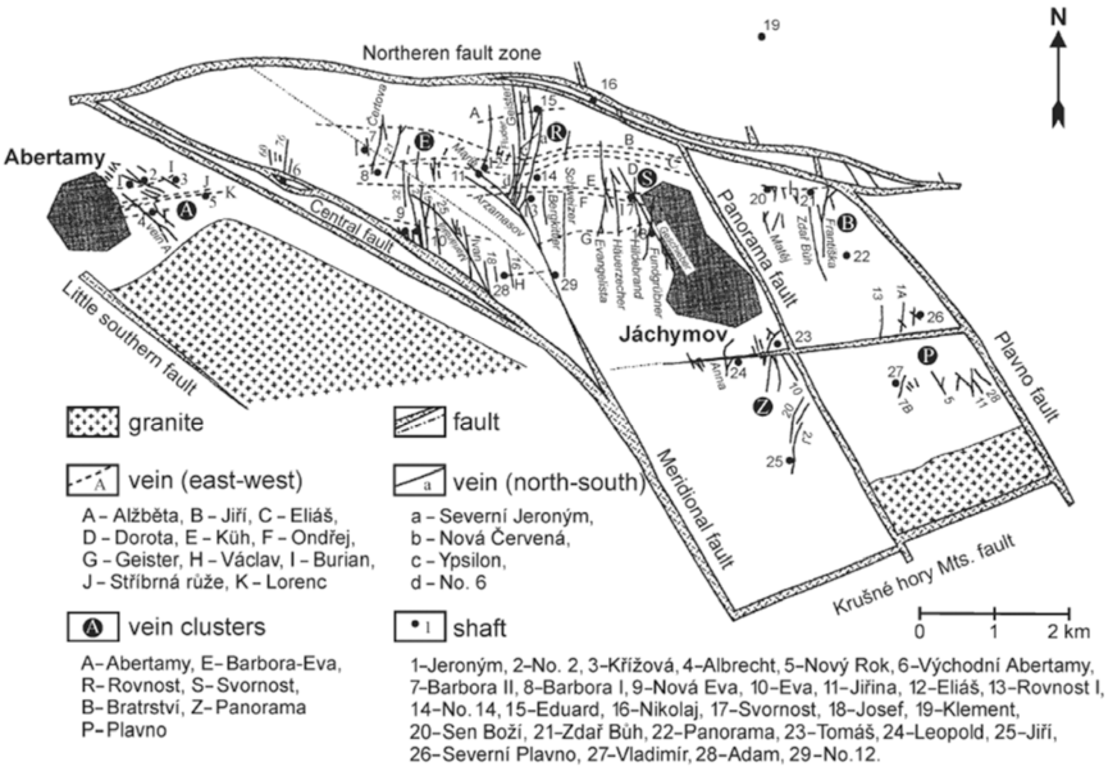

***Fig. 12** Structural map of the Jáchymov ore district, modified after Ondruš et al. (1997a).*

The veins in the direction E-W marked "jitřní"/"Morgen gänge" (morning veins) are often without any ore mineralization or only locally mineralized, namely on the crossings with the veins of other directions. The gangue is formed by tectonic–clay and mylonite fragments of the surrounding rock. Their extent is several kilometres and they are 0.5-1m thick (rarely more). In the past they were mostly used for long heading adits used as cross adits, due to their softer filling which was easier to break. Among the most famous ones there are the veins Küh, Andreas, Geier, Elias and others.

These veins are cross-cut by the important veins of the direction N-S marked as "půlnoční"/Mitternachtsgänge (midnight veins), that carried industrially important mineralization. They extend to only a few hundred metres and their thickness is very variable, from several centimetres to metres, and is changing on a very short distance. The main vein is often accompanied by several apophyses which are often more rich than the main vein itself. Ore lenses and accumulations are usually concentrated in the veins splitting or crossings (called „Schärungs"). The mineralization within the vein vertically is not distributed equally, but in the ore-bodies called chimney. To the depth the number of veins is less, only few, most important veins remain; the ore mineralization continues transiting from mica schist series to underlying granite of the Karlovy Vary massive.

There are few so called ore junctions or bundles consisting of crossings of midnight and morning veins, where important mineralization was mined. It is going namely about bundle Svornost (with most important N-S vein Geschieber, Hildebrand, Johannes Evangelist, Becken), Rovnost I (Geister, Schweitzer, Bergkittler, Roten Gänge), Bratrství (veins Francizska, Zdař Bůh) and several else (Ondruš et al. 1997, 2003; Horák 2000b).

Mineralogical characterization of the area

Jáchymov ore district is a typical example of the five-element formation Ag-Co-Ni-Bi-As and U-formation in the Czech part of the Erzgebirge Mountains. It is a vein hydrothermal deposit, medium temperate. The mineral richness of the veins itself is a product of an array of independent time-separated and chemically specific phases of mineralization. A schematic sequence of hypogenic mineralization stages are based on paper of Ondruš et al. 2003.

Fig. 13 A) *Black-violet antozonite (fluorite) in a dolomitic carbonate (hematitized) with uraninite and older tetrahedrite on the N-S vein;* ***B)*** *Arsenic accumulation (black body) on the crossing of midnight vein Geschieber and morning vein Geier. Besides native arsenic, traces of cementation silver, rare proustite-pyrargyrite minerals, pseudomorphoses of sulphur after argentite and many recently formed As-minerals as kaatialaite, arsenolite and claudetite are present there. Svornost pit, 10th level, photo J. Plášil.*

1) Sn-W sulphoarsenide stage. This stage is related to the autometamorphism of younger granite, underlying the whole district. It has no relation to the younger five-element mineralization. The typical representants are: milky quartz, pyrite, arsenopyrite, tourmaline, phlogopite, tungstenian rutile, cassiterite, molybdenite, chalcopyrite, tennantite, freibergite, aikinite, matildite, dark sphalerite, galena, stannite, kësterite, mawsonite and gersdorffite.

2) Ore-free quartz stage. Chalcedony-like ferruginous quartz, (Fe, Ca) carbonates, light-green fluorite.

3) Carbonate-uraninite stage. Dolomitic carbonate coloured red by hematite, uraninite, pyrite and black-violet fluorite (antozonite) (Fig. 13 A).

4) Arsenide stage. silver paragenesis → native silver, nickeline, rammelsbergite, nickel-skutterudite.
bismuth paragenesis → bismuth, skutterudite, rammelsbergite-safflorite.
arsenide paragenesis (free of native metals) → nickeline, löllingite, rammelsbergite, nickel-skutterudite, skutterudite, gersdoffite, argentite.

5) Arsenic-sulphide stage. Arsenic (Fig. 13 B), realgar, proustite-pyrargyrite, pyrite, löllingite, argentopyrite, sternbergite, stephanite.

6) Sulphide stage. Pyrite, marcasite, galena, sphalerite, chalcopyrite, calcite.

7) Post-ore stage. Manganoan calcite, ferruginous quartz, chalcedony-like quartz to opal, flurite, barite.

9) Supergene mineralization. Alteration of primary minerals under oxidizing conditions resulted in formation of numerous supergene minerals, either those found in the leached zone of oxidation, namely at the outcrop parts of the veins, or those formed recently in the environment of the old mining adits. For many minerals Jáchymov is a type locality; very famous are uranyl, $(UO_2)^{2+}$, containing supergene minerals, including uranyl carbonates (type locality for voglite, schröckingerite, albrechtschraufite, čejkaite, agricolaite), phosphates (torbernite), arsenates (metarauchite), silicates (uranophane-β) and sulphates (johannite, zippeite, nickelzippeite, uranopilite, jáchymovite, pseudojohannite, sejkoraite-(Y)) (Tvrdý and Plášil 2010).
Up to 430 minerals, both primary and supergene, have been discovered and described from Jáchymov up to now (latest figure counted by Jakub Plášil in February 2011).

Field trip itinerary – Jáchymov

STOP 1 – Schweizer vein mining field

The majority of accessible outcrops of the veins within Jáchymov ore distrcit show a relatively poor mineral associations; for the outcrop parts a nearly complete leaching of ore components is characteristic, only sporadic occurrences of uranium minerals (such as phosphates/arsenates torbernite, autunite, walpurgite; and silicates uranophane, kasolite), minerals of bismuth (bismutite, bismutoferrite), copper (malachite, mixite) and lead (anglesite, pyromorphite). A typical scheme of vein profile to the depth (Fig. 14), starting with a leached oxidation zone, enriched oxidation zone and cementation zone above zone formed from hypogen unchanched minerals is recorded only on Geschieber (Svornost mine), Geister and partly on Červené veins (Rovnost mine).

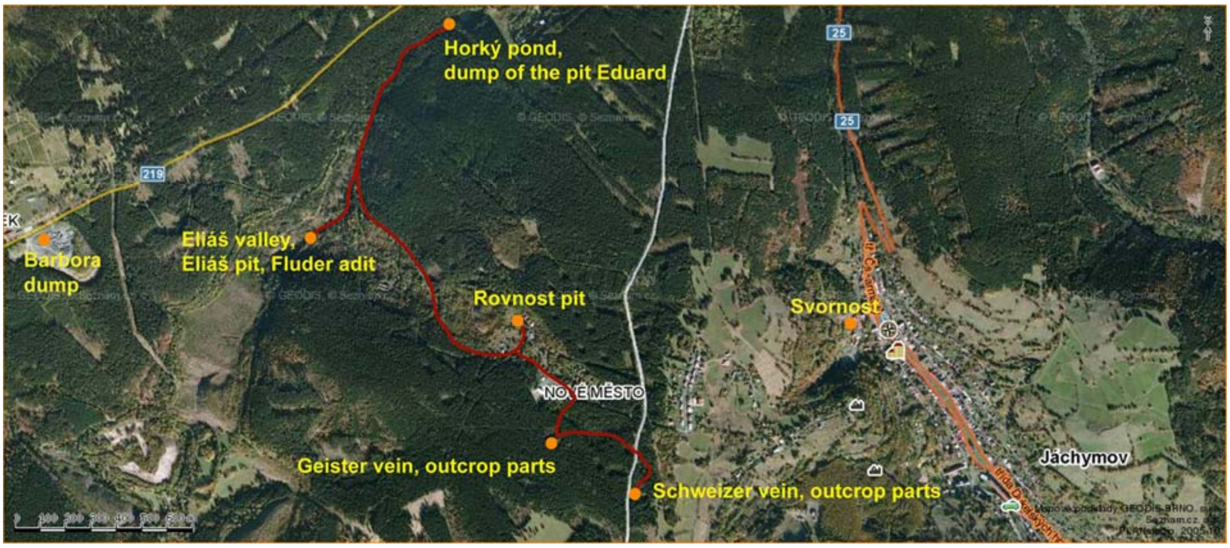

Fig. 14 *Plan of the guided tour, the outcrop part of the Jáchymov deposit (modified after GEODIS).*

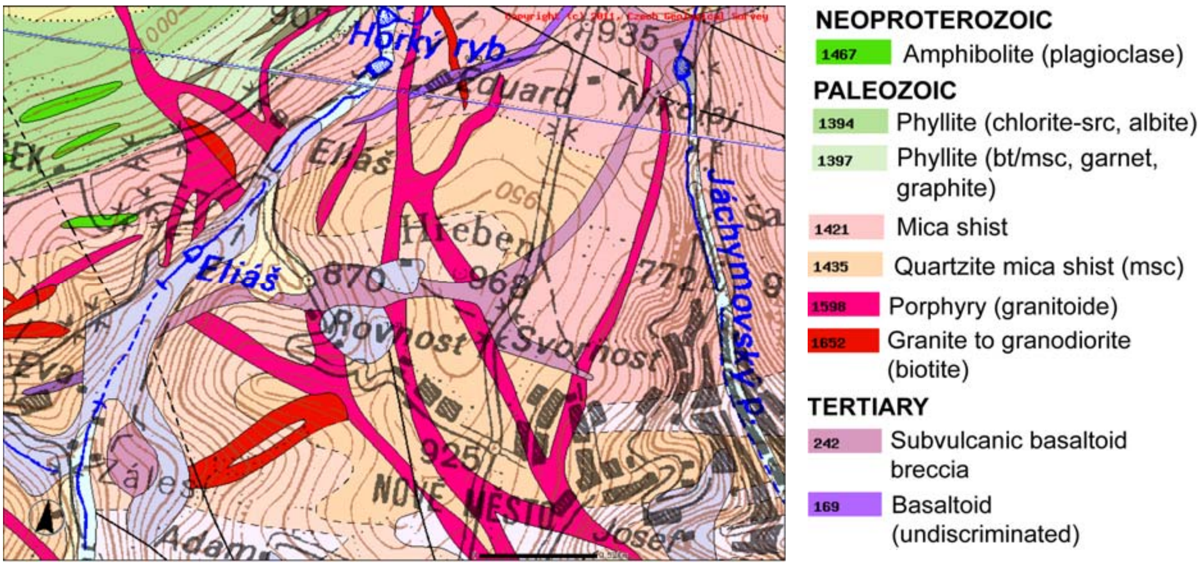

Fig. 15 *Schematic geological map of the guided field-trip area, modified from www.geology.cz.*

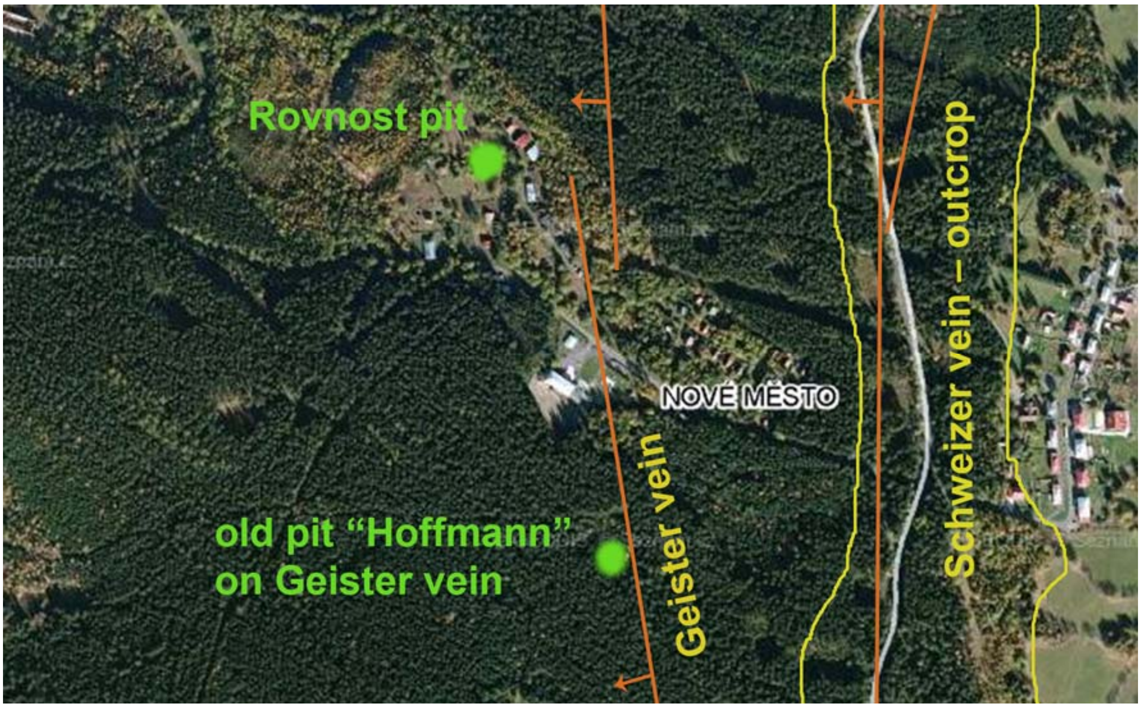

Fig. 16 *Schematic plan of the vein situation (displaying just path of the midnight veins) in the Rovnost area, original map by GEODIS.*

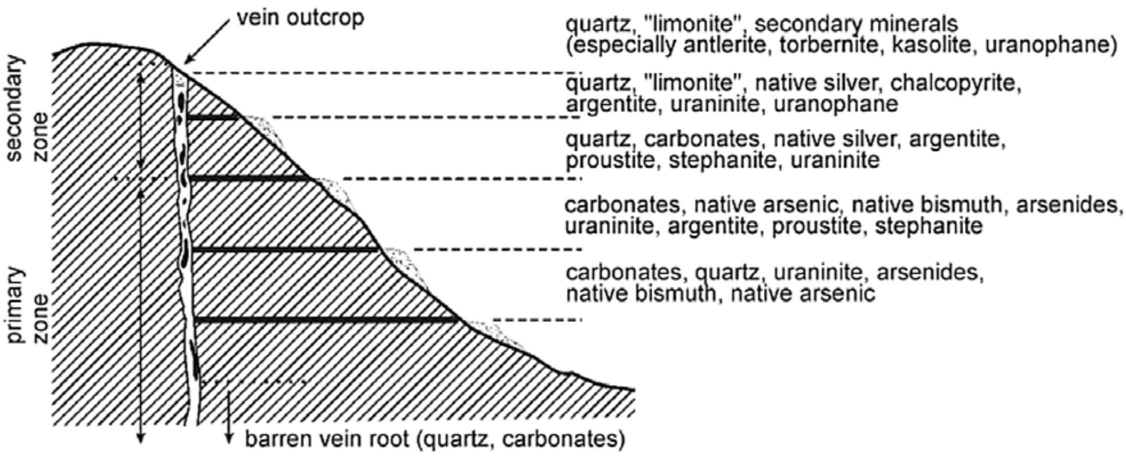

Fig. 17 *Schematic vertical profile of the five-element formation vein, from Ondruš et al. (2003b).*

Schweizer vein is one of the most important veins of the deposit of the N-S direction and inclination to the west. It is opened by mining activities from the surface to the 12th level of the Rovnost pit (~ 800 m under surface) in length of 1 km. The typical average thickness of the vein was between 10 and 50 cm (Fig. 18) with a total U production 179.8 t (after Pluskal 1998). The outcrop parts of the vein Schweizer were opened by tens to hundred shallow shafts and diggings during the first quarter of the 16th century. The zone of cementation enrichment of the vein was localized near the surface, therefore the finds of enormous pieces of natives silver and acanthite are documented from that times, namely in the works of renaissance writers, Georgius Agricola and Johannes Mathesius.

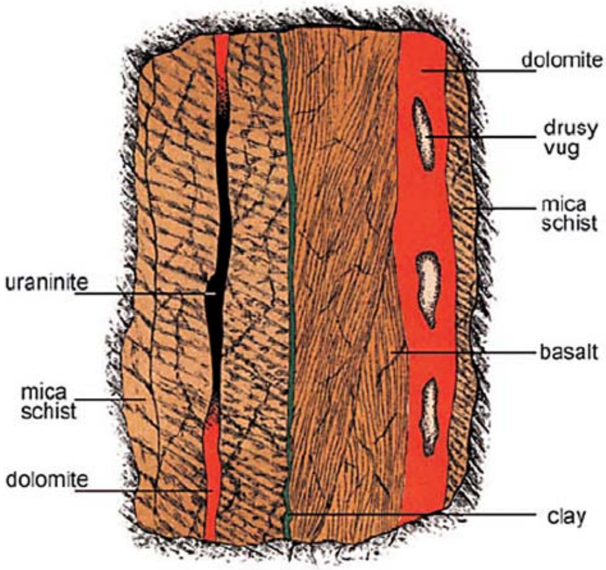

Fig. 18 *Schematic profile of vein Schweizer on 1st Werner level, Rovnost I shaft, drawn by J. Hozák (1889), from Babánek (1981).*

However the field situation is blurred due to latter mining activity focused on uranium exploitation, because Schweitzer vein and its northern apophysis as well as it's southern apophysis, called Hieronymus, was very rich on uraninite, down from the surface. During 1950'ies the prospect pit "Švýcar" was placed in this area, with the main purpose, for mining the rich near-surface ore-stocks in the area that was not available through winning from the Rovnost pit. The huge dump remaining after this small shaft was replaced due to an increased content of the remaining ore for manufacturing in the treatment plant. In the remnants of the former dump and in the dump material distributed over the nowadays still there is possibility of find the radioactive material.

Uraninite is the most ussual phase, less often are secondary alteration products such as sulphuric yellow uranopilite $(UO_2)_6(SO_4)O_2(OH)_6(H_2O)_6](H_2O)_8$, or rare deliensite $Fe(UO_2)_2(SO_4)_2(OH)_2(H_2O)_3$. Uranyl phosphates are quite common there, namely so called "uranium micas" torbernite $Cu(UO_2)_2(PO_4)_2(H_2O)_{12}$ and autunite $Ca(UO_2)_2(PO_4)_2(H_2O)_{12}$, same as hydrated uranyl arsenate of bismuth, walpurgite $Bi_4(UO_2)(AsO_4)_2O_4(H_2O)_2$.

STOP 2 – Geister vein mining field

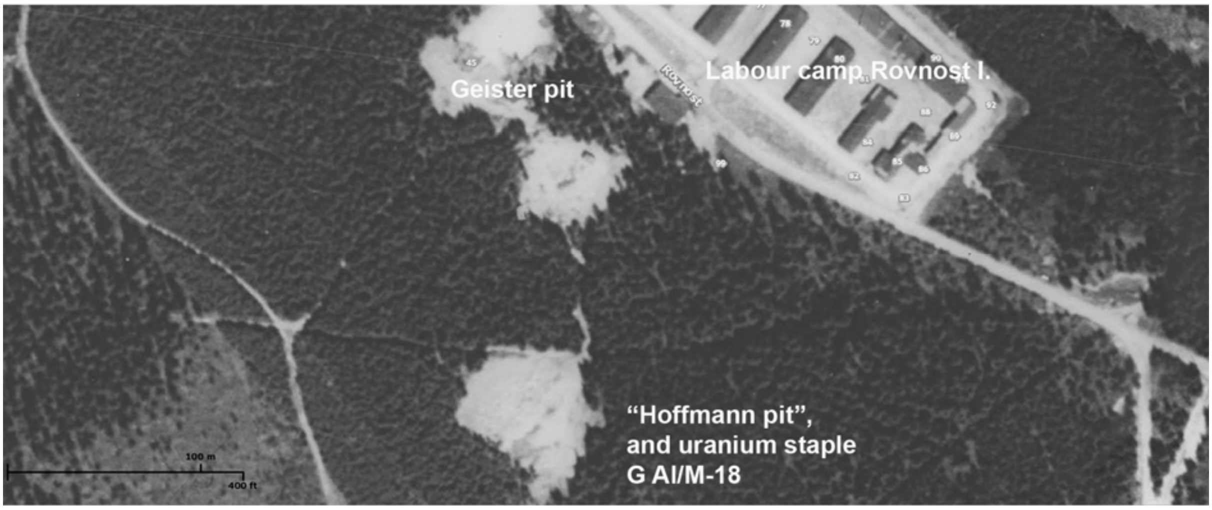

Fig. 19 *Area of the outcrop of the vein Geister on the airplane-photograph from 1950ties (courtesy of Vojenský kartografický ústav, Dobruška; modified from www.kontaminace.cenia.cz). On the picture is the area of the former labour camp Rovnost I., old Geister pit and "Hoffman pit" (locality no. 2) with uranium stope/raise going on the surface.*

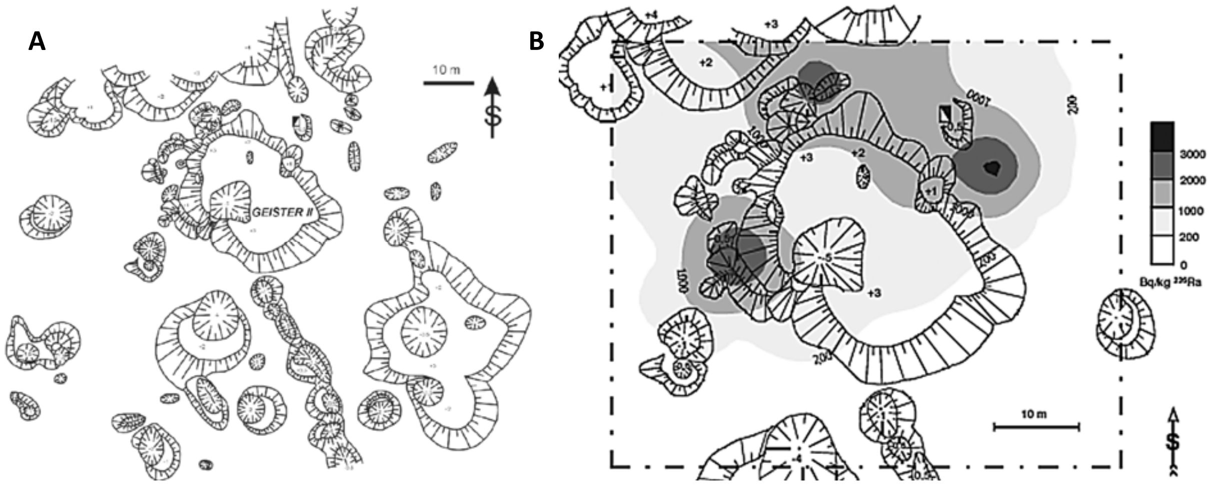

Fig. 20 A) *Terrain situation (morphology) in the vicinity of an old "Hoffmann" pit on the vein Geister. The position of the former uranium shallow shaft is marked;* ***B)*** *The activity of* ^{226}*Ra measured on the surface of the dump, in Pittauerová (2002).*

Geister vein, also called Polus Articus, Grünerhirschgang, or Heiligengeist gang, is an important N-S structure (350°-10°), which branches off the Meridional fault directly, when the fault crosses the axis of central anticline. It is opened by mining works from the surface down to the granite base. Typical average thickness of the vein is about 50 cm, the mineralized portions of the vein then around 10 cm. Vein itself was intensively mined yet from the 1530ties, when we have the first prove of the existence of mining there. We have the mining situation documented in the segment of the map, drawn up by the highest royal-court hetman for mining Kryštof Gendorf from the year 1589. The vein was rich on Ag-ores, beside that on Bi, Co and Ni. Yet from the surface, uraninite together with five elements occurred, in the first periods of mining deposed in the dump. This is the reason, why the morphological situation nowadays is quite complicated. The dumps were sorted for uranium ores in the first half of the 19th century, due to uranium colours production and later again during 1950ties, this is reflected in the fact, that the parts of the dump that have been dig up, correlates with the areas of the highest radioactivity (Fig. 20 B).

Geister vein is one of the famous mineralogical localities within the whole Jáchymov ore district. Below the zone of leaching, where only uranyl phosphates and silicates dominate, there is unusual rich alteration zone of supergene enrichment continuing to cementation zone sensū strictō. Lot of minerals, highly appreciated not only by mineral collectors were found in the old mining workings opened again after a long period of time (e.g., in the half of the 19th century by J. F. Vogl after hundreds of years, or in the early 1980ties after 30 years after the last mining activity). A splendid assemblage of secondary minerals of the subrecent or recent origin, formed in the environment of an old mining adit, results from the geochemical diversity of the elements present in the vein, such as U, V, As, P, Y, Cu, Co, Ni, Bi, Pb, Fe. The most interesting minerals of the subrecent/recent origin found in the old adits are uranyl sulphates (johannite, uranopilite), uranyl vanadates (tyuyamunite, curienite) and copper arsenates (lindackerite, veselovskýite, pradetite, geminite). The most known locality is 3. Geister lauf (3rd level of the Werner/Rovnost pit), and above all the place called Grüne Hirsh stope system (The green deer).

STOP 3 – Rovnost pit

Werner/Rovnost pit was opened in 1792 under the name Rudolf (after the crown-prince Rudolf) at the vein Geister, with the purpose to open more the mining field in the west-part of the Jáchymov mines, namely below the level of the Daniel hereditary drainage adit. It opened the Geister vein to the south from so-called "putzenwacke" zone (tuffitic breccia) to the south (Fig. 22), Schweizer vein in the deeper levels, Bergkittler vein and group of Rotergänge – Red veins. The opening was from the 1st (old level) down to the 12th Werner level (~ 650 m under the surface).

***Fig. 21** Werner/Rovnost pit with the work management building (left) (postcard, 1920ies).*

Later, the pit was renamed to Werner (in 1850) in honour of A. C. Wermer, the head-mining officer and mining expert from Säschen, in occasion of his 100 birthdays. During turn of 19th/20th century, Werner pit remained the main opening pit of the West part of Jáchymov deposit, where uranium ores were mined in the deeper levels of the above mentioned veins.

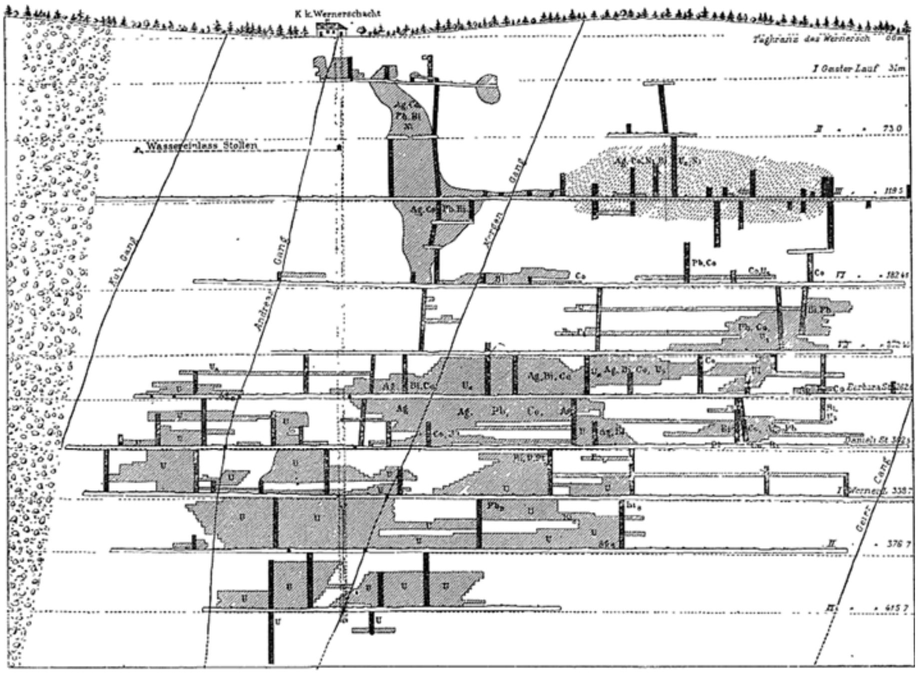

***Fig. 22** Schematic cross-section along Geister vein in the mining field of Werner/Rovnost pit. In the left part, the tuffitic breccia is sketched (after J. Štěp, in Štěp and Becke 1904).*

From 1945 after the WWII Rovnost pit was one of the first opened and prepared mines for mining the uranium ore for Soviet Union. From the end of 1940ties to 1961 the labour camp Rovnost I. was in operation, serves as a prison for people arrested and judged for political reason, who were used as a cheap labour for mining of the uranium ore. The conditions in the camp were horrible, the labour commanding officer was a sadist cattle, who tortured the prisoners. During the year thousands of people were stuck in there. During the mining era for uranium ore during 1950ties 227 t of U were mined from 20 vein structures there. From the 1961 Rovnost pit was prepared to be closed.

STOP 4 – Eliáš valley

From the Rovnost pit we are going downwards to the Eliáš valley. We are passing the forested dump of Rovnost pit on the right side. In the middle of the hill, on the left side is an old dump of Vogelsang adit, and the huge concrete building of the former turbo-compressor unit. The appearance of the valley changed dramatically few times during the 1950ties, first due to the mining itself and then during recultivation of the former mining activity, because the State enterprise had no interest in preservation of any remnants after uranium mining.

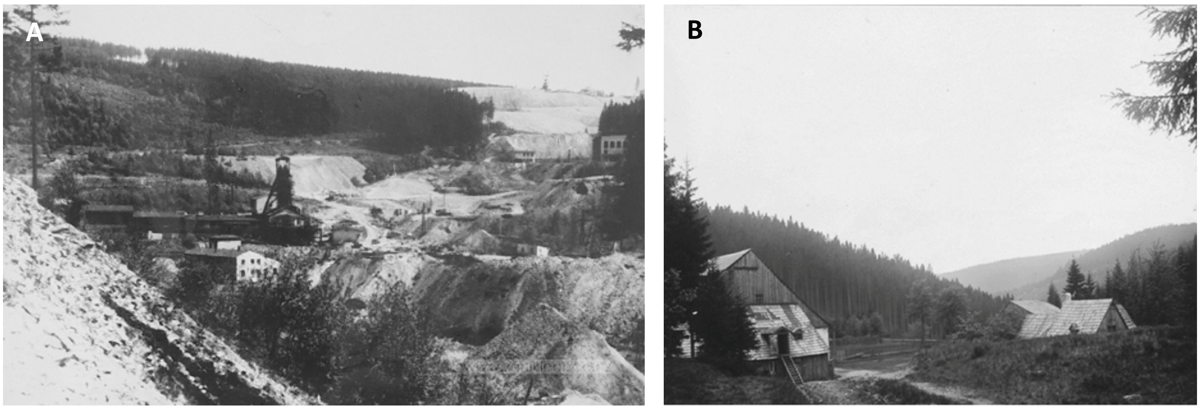

Fig. 23 A) *Eliáš valley during 1950ties. Jiřina pit in the centre with dumps and buildings of the treatment plant (below), main turbo–compressor hall (right side by the forest) and the large dumps of the Rovnost pit with the shaft tower (upper part right), the picture by courtesy of N. Weber;* ***B)*** *Eliáš valley with the Eliáš inclined shaft (left) and probably the house of the mining sworn (Berggeschworener) (right). The situation in the year 1909 (original Deutsche Fotothek).*

We are passing the race system that will be explained later on locality no. 5 – Heinz pond. At the bottom of the valley is our next stop – the area of former Eliáš inclined shaft, Jiřina uranium shaft, Eliáš adit and Fluder adit.

At the place of symbolic wooden cross the former shaft Eliáš was situated. Eliáš was the first mining work opening the west part of the Jáchymov deposit yet in 16th century, namely the upper parts of the vein Fiedler, Fluder, Elias, Johannes Silbermüller, a group of Red veins (Roter gang, Alter Roter Gang, Roter Gang Liegendtrumm) and Hieronymus vein. At the opposite side of the valley over the stream, Fluder adit is situated (Fig. 23 B), opening the vein of the same name.

Elias incline pit was the main mining work in the western part of Jáchymov mines till 1792, when the Rudolf (later Werner/Rovnost) shaft begun to be put down. During 19th century both pit operated together, mining namely upper parts of the vein Geister (Werner) and the veins down to the Barbora hereditary adit (Eliáš). As a mining officer called “Berggeschworener” (sworn), the well-known Josef Florian Vogl (1818-1896) was employed there. At first amateur mineralogist, who described few new type minerals from Jáchymov and wrote a famous book “Gangverhältnisse und Mineralreichthum Joachimsthals” (Vein conditions and mineral richness in Jáchymov); in this book he described 30 new minerals occurring in Jáchymov, increasing the number of known ones from 50 to 80 species. In the year 1892 all mining works at the Eliáš inclined shaft stopped and the pit itself was landed up. Then in

1950ties Eliáš shaft was opened again, but via parallel shaft made by the state enterprise Jáchymov mines, and was used namely for venting, while as the pulley shaft Jiřina pit, which is in the vicinity, was used. As miners, the political prisoners from the labour camp Eliáš.

STOP 5 – Heinz pond

Heinz pond is one of the mine-ponds utilizing the natural accumulation area for water, Eliáš valley, namely it's ending in lying more than 930 meters above the sea with other two ponds, namely the Seidl pond (~ 980 m. a. s.). These ponds were constructed together with the race system conducting the technological water at primarily down the Eliáš valley to Eliáš pit. Later when the pit had been less important, the new race was constructed with it's termination in the area of the nowadays Turbocompressor hall, where it reached so called Wassereinlass stollen, leading to Werner pit at the depth of ~ 78 meters (Fig. 24).

Fig. 24 *An old map of the Fluder adit drawn by mining officer J. Hozák in 1888 (courtesy of Geofond).*

Then the water fall down to the 3rd Geister level, where the turbines were installed that drive the hoisting machine to transport the material from 3rd level to the level of the adit and then through the adit to the surface. Hoisting machine was renovated twice; when the Werner pit reached the deeper parts this equipment had been removed. From the 3rd level technological water continued through underground via Albrecht adit above Svornost shaft, where it was led to the machines of Svornost and then it has been released to the Jáchymov stream. Behind the pond, there is a large dump of the uranium shaft Eduard. The cold water, rich on dissolved oxygen and very poor on nutrients is hosting very limited, but interesting flora and fauna. Shoals of brook minnow, occasionally the mountain eft and grass-frog occur. In the cavities of the dam and shores nests periodically the water ouzel and the grey wagtail.

We will continue our trip upwards through the ski slope, that is by the way an important botanical locality, characterized by a extremely cold weather there with a rich rainfall (one of the most in Czech Republic ever). Diphasiastrum alpinum, his home is a cold Northern Europe, leopard's bane and common wintergreen occur there. Our trip ends by the route in the area of the former labour camp Nikolaj (Nicolaus).

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ABSTRACT VOLUME

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