11th Annual Meeting

of the SGA Baltic Student Chapter

Kraków, Poland

October 20-25, 2019

AGH University of Science and Technology

Faculty of Geology, Geophysics and Environmental Protection
Department of Economic Geology

Dear Colleagues

On behalf of the Organizing Committee, I would like to extend a warm welcome to the participants of the SGA Baltic Student Chapter Meeting at the AGH University of Science and Technology in Kraków, Poland.

The aim of this annual event is to give the opportunity to gather together students from Poland, Sweden and Finland but geology has no borders so I am glad that this year we have guests from all around the world. This year marks 10th anniversary of establishing Baltic Student Chapter and I am delighted you are celebrating with us!

I would like to express sincere gratitude to Professor Sarah Gleeson and Professor Murray Hitzman who agreed to share their knowledge of ore deposits and prepared for us two-day short course.

I would like to thank Professor Anna Siwik, AGH UST Vice-Rector for Student Affairs and Professor Jacek Matyszkiewicz, Dean of the Faculty of Geology, Geophysics and Environmental Protection, for financial support which helped us organize this event.

I would like to express special acknowledge to the Society for Geology Applied to Mineral Deposits, who supported financially the event and enabled us to be here. I would also like to thank the Society of Economic Geologists for the support via Thayer Lindsley Visiting Lecturer Programm.

We wish you all a productive meeting and a pleasant stay in Kraków.

Krzysztof Foltyn
President of the SGA Baltic Student Chapter

Organizing committee:

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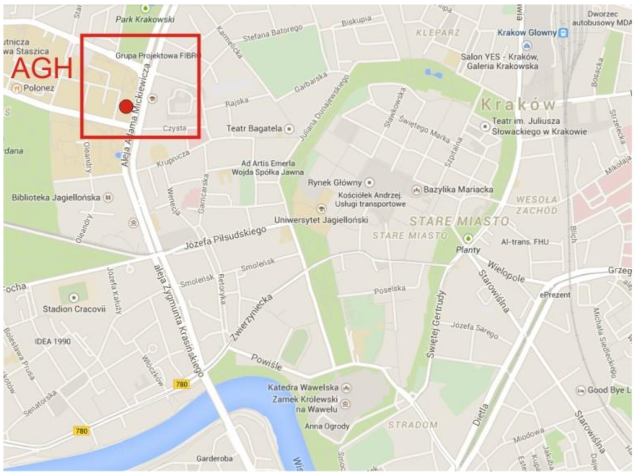
MEETING VENUE

The meeting takes place at the AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection (A0 building)

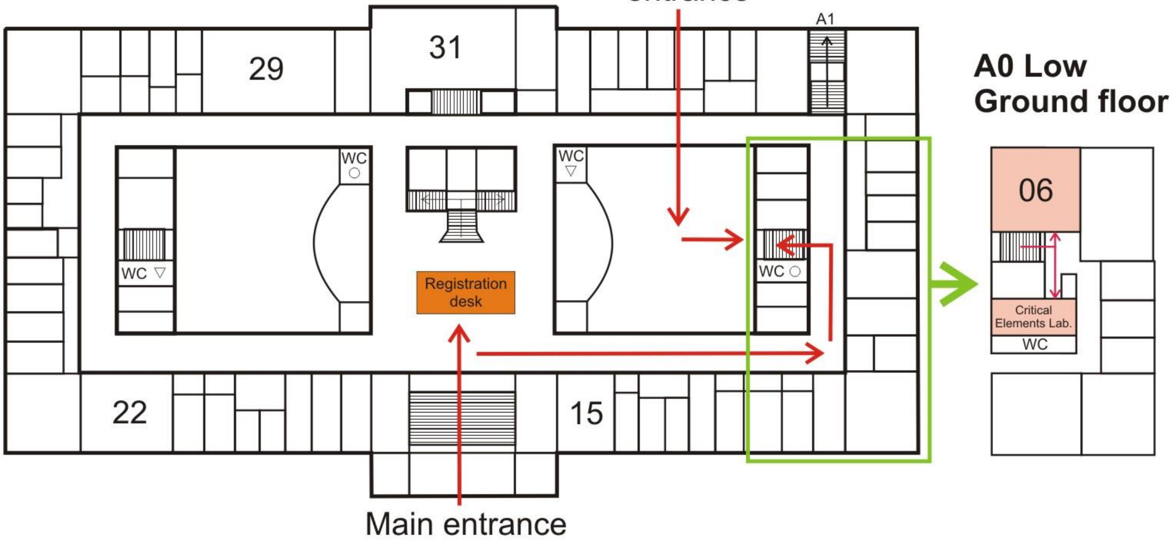


The meeting takes place at the AGH University of Science and Technology, Faculty of Geology, Geophysics and Environmental Protection (A0 building)

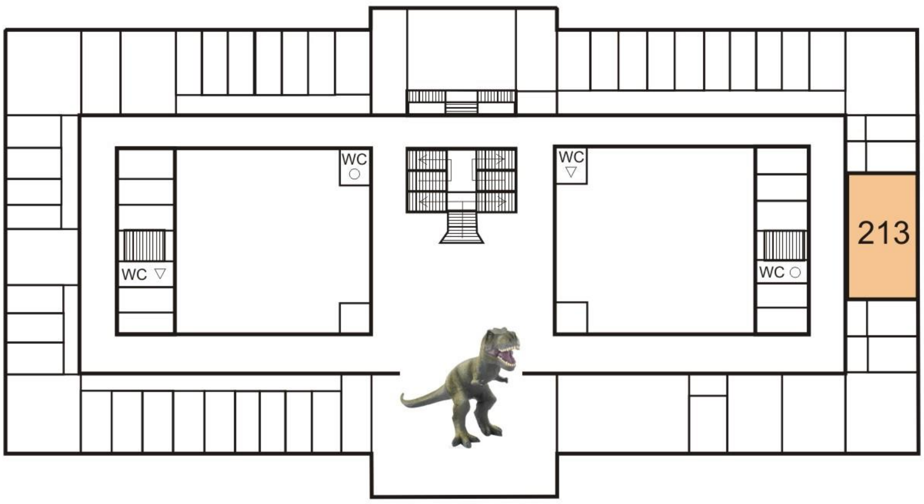
Registration deck is located in the main hall of A0 building, close to the main entrance to the building.

Lecture room (213) is located at the second floor of the A0 building.

A0 Ground floor



A0 Second floor



MEETING SCHEDULE

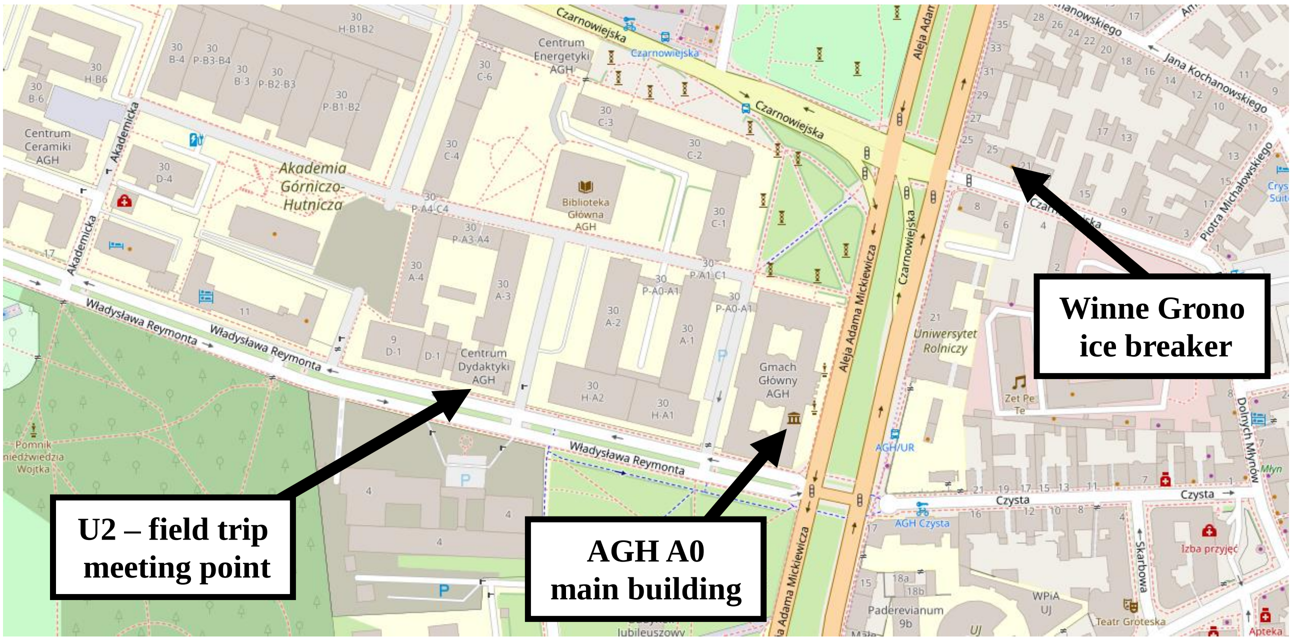
October 19 (Saturday)

18.00 icebreaker (Winne Grono, Czarnowiejska 23 Street)

October 20 (Sunday)

12.00-15.00 registration: A-0 buiding, front entrance

14.00 "Kupferschiefer" group meeting point at U2 building AGH, bus leaves to Głogów



October 21 (Monday)

"Kupferschiefer" group – visit in the Sieroszowice-Polkowice mine

"Pomorzany" group – visit in the Wieliczka salt mine, meeting point A0 AGH building 9.00

October 22 (Tuesday) "Zinc day"

(A0 building, room 213)

8.50-9.00 Opening remarks

9.00-10.30 Introduction to Zn – prof. Sarah Gleeson

coffee break

10.45-12.15 Selwyn Basin - Macmillan Pass – prof. Sarah Gleeson

lunch break

14.00-15.30 Red Dog District; Australian mesoproterozoic Zn deposits – prof. Sarah Gleeson

coffee break

15.45-17.15 Irish type deposits – prof. Murray Hitzman

October 23 (Wednesday) "Copper day"

(A0 building, room 213)

9.00-10.00 Sedimentary rock-hosted stratiform copper ore sytems

coffee break

10.15-11.00 Porcupine Mtns. District, Michigan (White Pine)

11.00-12.15 Kupferschiefer

lunch break

14.00-15.00 Chu-Sarysu Basin (Kazahkstan)

coffee break

15.15-17.00 Central African Copperbelt

17.00 - Kupferschiefer samples exhibition

October 24 (Thursday)

6.30 "Pomorzany" group – visit in the "Pomorzany mine" - meeting point AGH U2 building at 6.30 am

8.00 "Kupferschiefer" group – visit in the Wieliczka salt mine, meeting point AGH A0 building at 8 am

Lunch break

14.30 -14.45 10 years of the SGA Student Baltic Chapter

14.45 – 15.00 EXplORE – new MSC programme in exploration

15.00 – 15.30 Dr hab. inż. Dariusz Więcław: Organic matter and the Kupferschiefer

15.30 – 16.00 prof. Adam Piestrzyński: The Kupferschiefer

16.00 -16.30 - Roland Butler: The Voisey's Bay deposit

16.30-16.45 coffee break

16.45 - 17.30 – seminar session part 1

17.30 - 18.00 SGA-SEG Student Chapters presentations

October 25 (Friday)

9.00 - 11.00 seminar session part 2

coffee break

11.15 – GeoQuiz

Seminar session

Part 1 (Thursday)

Aleksandra FURTAK: Mineralization in the secondary oxidation zone of copper ore deposit, Polkowice-Sieroszowice mine (Poland)

Jakub WĘGRZYNOWICZ: Chemical composition of bismuthinite – aikinite series from Mazhiq (Kosovo)

Part 2 (Friday):

Rafael BAIETA: Environmental impact assessment of a Pb, Zn smelter using soil and tree ring elemental and isotopic geochemistry in Kabwe, Zambia

Viktor BERTRANDSSON ERLANDSSON: Investigating the origins of the sediment-hosted Cu-Co Dolostone Ore Formation mineralization, Kunene Region, Northwestern Namibia

Krzysztof FOLTYN: Trace elements in sulfides from the Polish Kupferschiefer

Michal ROLL: Origin of secondary uranyl-carbonate minerals at Giftkies mine, Jáchymov, Czechia: possible climate implications?

Miguel QUINTANA: New vision of the Metallogenic belt of Upper Cretaceous Porphyries related to the Coastal Batholith, occurrence Cu-Mo in the south of Peru

Aung Myo THU: Mineralogical and geochemical characteristics of Cu-Ag from Kyaukse Sabe Taung copper deposit, western margin of the Shan Plateau, Myanmar

Sławomir MEDERSKI: Bi mineralization from eastern part of Hajvalia-Badovc-Kizhnica ore field (Kosovo)

ABSTRACTS

Mineralization in the secondary oxidation zone of copper ore deposit, Polkowice-Sieroszowice mine (Poland)

Aleksandra FURTAK[1*], Jadwiga PIECZONKA[1]

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Polkowice-Sieroszowice mine is located in Lower Silesia (SW Poland). Copper deposit itself is a part of Fore-Sudetic Monocline, on the border of the Lower and Upper Permian strata [1]. It is known as a stratoidal type of deposit. In older papers it was described as a Kupferschiefer type. The main commodity is copper and the by-products are Ag, Au, Ni, Pb, Pt-Pd, Se i Re. Precious metals, formed in the secondary oxidation zone, occur in Polkowice-Sieroszowice mining area.

Samples for this study were collected from the Sieroszowice area. They represent secondary oxidation zone occurrence in three main lithologies: sandstone, carbonate rocks and shales. Thin sections were prepared and investigated with transmitted light microscopy. EMPA-WDS and EDS analyses were done as well.

In analyzed profile secondary oxidation encompass the sandstone, clay shale, dolomitic shale and partly dolomite. It results in a red colouration of the rocks, which is in form of lenses, spots, veins and laminas [3]. The red spots are of epigenetic origin and were formed by reaction of oxidizing solutions ascending from the basement with the surrounding rocks [1]. Oxidizing solutions penetrated the rock complex after the formation of economic-grade copper mineralization [2] and redistributed it upwards in profile. Analyses confirmed that in the secondary oxidation zones the copper content is relatively low (i.e less than 0,0X% in the shale). Cu mineralization is represented mainly by chalcopyrite, bornite, chalcocite and covellite. Poor Cu content is compensated by precious metals occurrence. The EDS and WDS analyses conducted on sample 1/5 (sandstone) reveal the occurrence of gold, electrum, Hg-bearing electrum and tetraauricupride.

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Chemical composition of bismuthinite – aikinite series from Mazhiq (Kosovo).

Jakub WĘGRZYNOWICZ[1*], Jaroslav PRŠEK[1], Sławomir MEDERSKI[1], Katarzyna KWIECIEŃ[1]

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Chemical analysis of lead-bismuth and lead-bismuth-copper sulphosalts from Mazhiq in northern Kosovo were performed using electron micro probe analyzer. Bismuthinite, krupkaite, aikinite, cosalite and native bismuth were identified as main Bi-bearing minerals. Derivatives of bismuthinite-aikinite series are characterized by broad degree of aikinite-type of substitution in individual members.

Investigated area is located in the middle of 80-km-long Trepça Mineral Belt in northern Kosovo, within Vardar tectonic zone - NNW-SSE trending regional suture between the Serbo-Kosovaro-Macedonian Massif to the east and the Dinarides to the west (Hyseni et al. 2010). Ore mineralization is linked to Oligocene-Miocene magmatic activity of andesitic, trachytic and latitic composition (Kołodziejczyk et al. 2017).

Bismuthinite forms elongated needle-like crystals up to few centimeters long, crosscutting carbonates or chalcopyrite. It occurs also as aggregates of anhedral crystals in interstices between quartz crystals. Degree of aikinite-type substitution (on basis of Topa et al. 2002) has values from n_a=0.56 to n_a=12.93 in samples from Mazhiq I and n_a=0.53 to n_a=6.15 in samples from Mazhiq II. Krupkaite ($PbCuBi_3S_6$) forms thin (usually to 10 µm) fringes on boundaries of bismuthinite crystals or irregular elongated exolutions within bismuthinite. Degree of aikinite-type substitution varies from n_a=47.50 to n_a=59.62. Aikinite ($PbCuBiS_3$) occurs similarly as krupkaite. Usually these minerals are products of bismuthinite or cosalite replacement. Degree of aikinite-type substitution varies from n_a=79.76 to n_a=93.91. Occurrence of only these three minerals of bismuthinite – aikinite series indicates low fluid temperature (up to 250˚C) and rather constant crystallization conditions (Topa et al. 2002). Similiar mineralization occurs in other localities in Vardar Zone (as Kizhnica region), which could indicate congruent hydrothermal conditions on a wider scale.

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Environmental impact assessment of a Pb, Zn smelter using soil and tree ring elemental and isotopic geochemistry in Kabwe, Zambia

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Due to its historical Pb, Zn, Ag, Cd and Cu mines and associated smelter, Kabwe in Zambia is known to be one of the most polluted cities in the world.

Four soil profiles Pb, Zn and Cu contamination was assessed around the smelter and in remote locations, using Q-ICPMS for trace metal elemental and Pb isotopic measurements. A sequential extraction procedure (SEP) approach was used to obtain a detailed understanding of the vertical behaviour of the contaminants and its availability for plant uptake. Slags Pb isotopic ratios were also determined. Furthermore, tree rings of local pine trees (*Pinus Montezumae*) were collected and analysed for the same contaminants and Pb isotopes coupled with C isotopes. Results were compared to the smelter production historical records in order to assess the viability of these trees as environmental archive.

Results show that contamination is exclusive to the topsoil and is greater in soils closer to the smelter, which are highly contaminated (max: 16000 mg/kg Pb; 140000 mg/kg Zn; 600 mg/kg Cu). Remote soils have much lower topsoil concentrations (min: 61 mg/kg Pb; 351 mg/kg Zn; 21 mg/kg Cu). Interestingly, the greatest contaminant concentrations were found in the tree furthest from the source of pollution (max.: Pb, 6.48 mg/kg; Zn, 10.6 mg/kg; Cu, 10.2 mg/kg). Particle size of wind-blown dump dust decreases with distance. A hypothesis is considered that these would be more easily adsorbed and absorbed by tree bark and leaves. This suggests that above-ground tree uptake is more important than soil uptake for the selected elements. This phenomenon has been observed in previous studies (Csavina, 2011 and Mihaljevic, 2015).

Slag Pb isotopic ratios average at $^{206}Pb/^{207}Pb$ = 1.15; $^{208}Pb/^{206}Pb$ = 2.15; for tree rings; both sites: $^{206}Pb/^{207}Pb$ = 1.15; $^{208}Pb/^{206}Pb$ = 2.13; and in top soils, close to smelter: $^{206}Pb/^{207}Pb$ = 1.15; $^{208}Pb/^{206}Pb$ = 2.12; and in remote location: $^{206}Pb/^{207}Pb$ =1.14; $^{208}Pb/^{206}Pb$ = 2.15.

Archives show three major changes in smelter production; increase from late 1950's to early 1970's and a subsequent decrease till the closure of the smelter in 1994 with a peak in production in the early 1980's. There seems to be a correlation between Pb production and Pb uptake and Pb and C isotopic ratio variations within a 5 to 10 years delay.

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Investigating the origins of the sediment-hosted Cu-Co Dolostone Ore Formation mineralization, Kunene Region, Northwestern Namibia

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A significant Co mineralization has recently been discovered in the Kunene region, northwestern Namibia. The mineralization is referred to as the Dolostone Ore Formation (DOF) and is defined by Cu, Co, Zn, Fe, Ni and Mn enrichment. The DOF ore horizon is hosted within Neoproterozoic calcareous shales and carbonates of the Ombombo Subgroup in the Damaran Supergroup. The Damaran Supergroup represent a transgressional succession from terrestrial rift sediments to a carbonate platform environment. It comprises the Neoproterozoic 'Snowball Earth' Chuos and Ghaub diamictite formations, and ends with a cap carbonate subgroup (Miller, 2008).

Typical DOF-sulfide assemblages consist of pyrite, pyrrhotite, chalcopyrite, sphalerite, galena and linnaeite-siegenite. Three Co-sulfide phases have been identified: euhedral linnaeite-siegenite, flames of jaipurite in pyrrhotite, and accessory cobaltite. Five different sulfide mineralization styles are found within the DOF horizon: disseminations, nodules, veins, breccias, and slump-like structures. Sulfide textures indicate the possibility of both diagenetic and epigenetic origin. Ore grades show a bell-shaped distribution, with a sharp footwall contact, whilst grading out into the hanging wall.

Although preliminary results suggest similarities to the Central African Copperbelt (CAB), several distinctions can be made when compared to sediment-hosted deposits within the CAB. The DOF-hosting shales are not the first reductive shales in the sedimentary succession. Furthermore, the lack of evaporites within the stratigraphic package is significant. Evaporites are believed to play a significant role in the genesis of the mineralizing fluids for most sediment-hosted copper deposits (e.g. Hitzman et al., 2005; 2010 & Kirkham, 2001). The ultimate aim of this study is to generate an appropriate metallogenic model for the DOF, which can be applied to exploration.

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Trace elements in sulfides from the Polish Kupferschiefer

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The black Upper Permian Kupferschiefer hosts the largest copper and silver deposits in Europe which occur along the southern margin of the Zechstein basin. It is stratigraphically positioned between the underlying siliciclastic red beds (Rotliegende) and the Zechstein limestones and all three lithologies host mineralization.

Samples with macroscopically visible sulfides (chalcopyrite, bornite and chalcocite) has been selected for LA-ICP-MS study. Trace element analyses were carried out at the Department of Applied Geosciences and Geophysics, Montanuniversität Leoben, Austria, using an ESI NWR213 Nd:YAG laser ablation system coupled to an Agilent 8800® triple quadrupole ICP-MS. The USGS powder pressed polysulfide reference material MASS-1 was used for quantification of the element content and the silicate glass reference material NIST 612 was used for quality control of the analyses. The following isotopes have been analyzed: ^{55}Mn, ^{57}Fe, ^{59}Co, ^{60}Ni, ^{63}Cu, ^{71}Ga, ^{74}Ge, ^{75}As, ^{82}Se, ^{95}Mo, ^{107}Ag, ^{111}Cd, ^{115}In, ^{118}Sn, ^{121}Sb, ^{201}Hg, ^{205}Tl, ^{208}Pb, ^{209}Bi.

Copper sulfides can contain trace elements at levels that are economic or could pose an environmental threat. In the case of the Kupferschiefer deposit, silver is along copper the main commodity and usually occur as substitution in the copper minerals, which is reflected in our results as significant Ag enrichment in bornite and chalcocite with content up to 3586 ppm and 1982 ppm respectively. In some chalcocites, Pb enrichment up to 721 ppm can be found. Concentrations of most trace elements are usually low, often at single ppm level. In contrast with bornite and chalcocite, analyzed chalcopyrite from the Kupferschiefer show significant variations in trace element concentration. They can contain Zn, Ge, As and Pb at the level of several thousand ppm, while Mn, Ni, Cd, Ag at the level of hundreds of ppm. Rhenium concentration in analyzed sulfides was very low (at background level). Many spots show increase in counts of Pd and Rh (but no for Pt) corresponding to concentrations of single ppm. Further investigation is needed to confirm whether this signal is valid or come from the isobaric interference.

Origin of secondary uranyl-carbonate minerals at Giftkies mine, Jáchymov, Czechia: possible climate implications?

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In this work, we have investigated uranyl carbonate minerals: rutherfordine, $UO_2(CO_3)$, agricolaite $K(UO_2)(CO_3)_3$ and liebigite $Ca_2(UO_2)(CO_3)_3$ $11H_2O$, all of them collected in former arsenic mine Giftkies, located near Jáchymov ore district *s.s.*, approximately 2 km NE direction from Northern fault. Uranyl carbonates are usually relatively soluble in aqueous solutions; aqueous uranyl-carbonate complexes are thermodynamically stable and they are responsible for migration of uranium in the environment on a large scale (Clark et al 1995). At the Giftkies mine are sharply developed vertical bodies of mica schist, intensively mineralized by arsenopyrite and less by chalcopyrite and tennantite. These minerals were a subject of the historical mining, besides As-mineralization there is a system of younger hydrothermal veins, cutting the rock bodies, mineralized by uraninite; gangue is dominantly represented by quartz, carbonate is lacking in fact. Rutherfordine forms rather inconspicuous aggregates of pale yellow color, only seldom of the bright yellow color that are more apparent. Nevertheless, these aggregates may cover large areas of the quartz fissures and thin veinlets, up to dozens of cm^2. Agricolaite is an extremely rare mineral, first described from this site (Skála et al. 2011). Forms bright yellow to yellow-greenish, from isometric to elongated crystals. Liebigite forms well-developed euhedral crystals of the yellow-greenish color and their aggregates that cover larger areas up to first tens of cm^2. Minerals were identified by powder X-ray diffraction, using PANalytical Empyrean diffractometer, with Cu*K*α radiation in the range from 3 °2θ to 70° 2θ at room temperature. For further interpretation more data were obtained. First we used non-destructive alpha spectrometry for radionuclides content and type of radioactive disequilibrium. Agricolaite and liebigite indicates subrecent ages and they are probably products of weathering processes, that took place in historical adits, only rutherfodine was dated by $^{230}Th/^{234}U$, giving us following ages: 3 725 ± 845 years and 3 470 ± 900 years. Second carbon and oxygen stable isotopes measurements were carried out. Third hydrochemistry of the studied site. From these data we suggest three main hypothesis of origin:

1. Precipitation due to cold and dry event during epiatlantic period.
2. Crystallization caused by mixing of meteoric waters and waters derivate from metamorphic basement.
3. Crystallization from subglacial waters from melting firn cover or glacial relict.

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New vision of the Metallogenic belt of Upper Cretaceous Porphyries related to the Coastal Batholith, occurrence Cu-Mo in the south of Peru

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The study area is located approximately 244 km SE from the city of Lima. The application of this study was made in order to find a possible exploration target and to analyze the relationship with others small porphyries through geological mapping, petrology, mineralogy and alteration, X-ray powder diffraction (XRD), fluid inclusions, geochemistry, optical microscopy and scanning electron microscopy (SEM) studies. The project is found in the valley of the Aylloque river, composed of granodiorites and rhyolites, integrated mineralogically by zeolites (chabasite) with radial fibrous shapes of centimetric sizes; they are on the edges of the cavities and with interstices filled out with iron oxides, sericite and chlorites (chamosite). It also presents small inclusions of pyrite and fine disseminations of epidote (clinozoisite).

On the other hand, it shows structures with orientation mainly NE-SW. Likewise, there are at least 2 types of intrusives related to the mineralization, one porphyritic andesite with weak phyllic - propylitic alteration and another rhyolite with propylitic alteration. The distribution of the concentrations of the main elements in the studied area follow mainly petrological and structural patterns, the molybdenum-copper concentrations have a linear relationship. According to fluid inclusions studies in the copper occurrence, they reveal that the greater efficiency of precipitation of these fluids are between the ranges of 220°- 320°C, precipitate that is clearly accommodated at temperatures of the propylitic and phyllic alteration, corroborated by petrographic and mineragraphic studies, as well as XRD. The concentrations of Mo and Cu are distributed in a similar way in the Tiabaya Unit, with concentrations from 1 up to 750 ppm, distributing homogeneously, there is a contrast of anomalies, of lower rank than those of the north, which vary from 1 up to 128 ppm of Mo, where it is directly related to the anomalies of Au (5.8 ppb) and Cu (0.1%), as Au and Cu values increase in content of TiO_2 up to 1.45%.

These data could indicate a clear vectorization, whereas the lowest precipitation temperatures are found in the distal zones from the porphyry. Thus, the spatial distribution of the mineralization follows complex physicochemical and petrological patterns, as well as the values of the anomalies found, it makes this a very promising area to explore continuously.

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Mineralogical and geochemical characteristics of Cu-Ag from Kyaukse Sabe Taung copper deposit, western margin of the Shan Plateau, Myanmar

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Myanmar has more than 70 copper occurrences, including world class high-sulfidation Cu ± Au deposits at Monywa *(Khin Zaw et al., 2017)*. The Kyaukse Sabe Taung copper deposit is located east of central Myanmar Tertiary basin and western margin of the Shan Plateau. There is a debate over origin of this deposit with propositions ranging from deformed MVT/Irish-type deposit or structurally controlled orogenic base metal–gold deposit *(Khin Zaw et al., 2017*). The majority of copper mineralization is hosted in the Middle Ordovician limestone of Wunbye Formation. Within this unit, most of the sulphide minerals occur disseminated in quartz veins, quartz-calcite veins and in fractures. The mineralized veins are generally horizontally trending, although some minor, vertical, younger veins occasionally cross-cut the horizontal veins.

The major quartz vein is generally trending NE-SW and dipping to the east. It is characterized by the presence of polymetallic mineralization composed of chalcopyrite, tetrahedrite, minor amount of pyrite, chalcocite, covellite, bornite and oxide minerals are tenorite, cuprite, azurite and malachite. Chalcopyrite, tetrahedrite and bornite represent hypogene ore and chalcocite and covellite are probably supergene as they occur in association with malachite and other oxide phases. Ag-Hg amalgams were found as free grains and coating of the quartz grain revealing that they represent late state of mineralization. The EPMA measurements of the silver grains showed that the content of Ag range from 73.40 to 98.55 wt.% and Hg is in the range from 2.15 to 26.69 wt.%. One analytical point had a chemical composition very closely to Eugenite (Ag_9Hg_2 – $Ag_{11}Hg_2$).

The percentage of copper in tetrahedrite is ranging from 39.31 wt.% to 40.17 wt.%. Fe content is on the level of 3.86 - 4.29 wt.%. The Ag content is ranging between 0.01 to 0.32 wt.%. Mercury content is 0.08 to 0.18 wt.%. In this deposit, several phases characterized with different Bi-Pb-Cu composition were identified. The Bi-sulfosalt minerals belong to hammarite - aikinite series and occur as intergrowths in pyrite and chalcopyrite. Bismuth sulfosalts contain 43.04 % Bi, 10.48 % Cu and 29.517 % Pb with $n_{aikinite}$ = 87.21 (Friedrichite), 51.924 % Bi, 23.469 % Pb and 8.148 % Cu with $n_{aikinite}$ = 66.45 (hammarite). The calculated $n_{aikinite}$ values range from 66.45 – 88.61 and the Cu:Pb ratio is from 1.03 to 1.16. Several grains have intermediate compositions between hammarite – friedrichite and fridrichite-aikinite

References:

Khin Zaw, Ye Myint Swe, Tin Aung Myint and Knight, J., 2017. Copper deposits of Myanmar. A.J. Barber., Khin Zaw., M.J. Crow., (eds.) Myanmar: geology, resources and tectonics, Geological Society Memoirs 48, London, 573–588.

Bi mineralization from eastern part of Hajvalia-Badovc-Kizhnica ore field (Kosovo)

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The study area is situated in the central part of the Kosovo, 9 km southeast of Prishtina within Vardar Zone. The area of interest is located in the eastern part of the Hajvalia-Badovc-Kizhnica ore field. The Hajvalia-Badovc-Kizhnica ore field is dominated by Paleozoic and Mesozoic magmatic, metamorphic (serpentinites, gneisses) and sedimentary rocks (flysch), Neogene volcanic rocks, and Pliocene sediments. Numerous mineralization styles including: veins, irregular metasomatic orebodies, stockwork-impregnation, skarns and listwaenites are observed within the ore field. Polymetallic mineralization is genetically related to the hydrothermal activity. Within the Trepça Mineral Belt Bi mineralization were previously described only in the area of the Stan Terg deposit e.g Kołodziejczyk et al. (2017) and Węgrzynowicz et al. (2019). Additionally, presence of native bismuth and bismuthinite associated with base metals sulphides and tellurides were reported in Slivovo Gold – Silver Project to the east of the Kizhnica deposit (Buerger & Giroux, 2016). The objective of this study was to describe new occurrences of bismuth minerals from the Kizhnica-Janjevo area, considering chemical composition as well as mineral paragenesis. The bismuth minerals were investigated by reflected light and EPMA analyses.

Bismuth minerals occur in polymetallic veins in Kizhnica andesite quarry close to the Kizhnica Pb-Zn-Ag deposit. Members of bismuthinite-aikinite series are associated with chalcopyrite, tetrahedrite, pyrite and hematite and form aggregates up to 200 µm. Minerals from bismuthinite – aikinite series are represented by aikinite (naik=96.66-84.07), krupkaite (n_{aik}=59.99-46.00), paarite (n_{aik}=41.92-41.97) and lindströmite (n_{aik}=65.00-64.21: above lindströmite field).

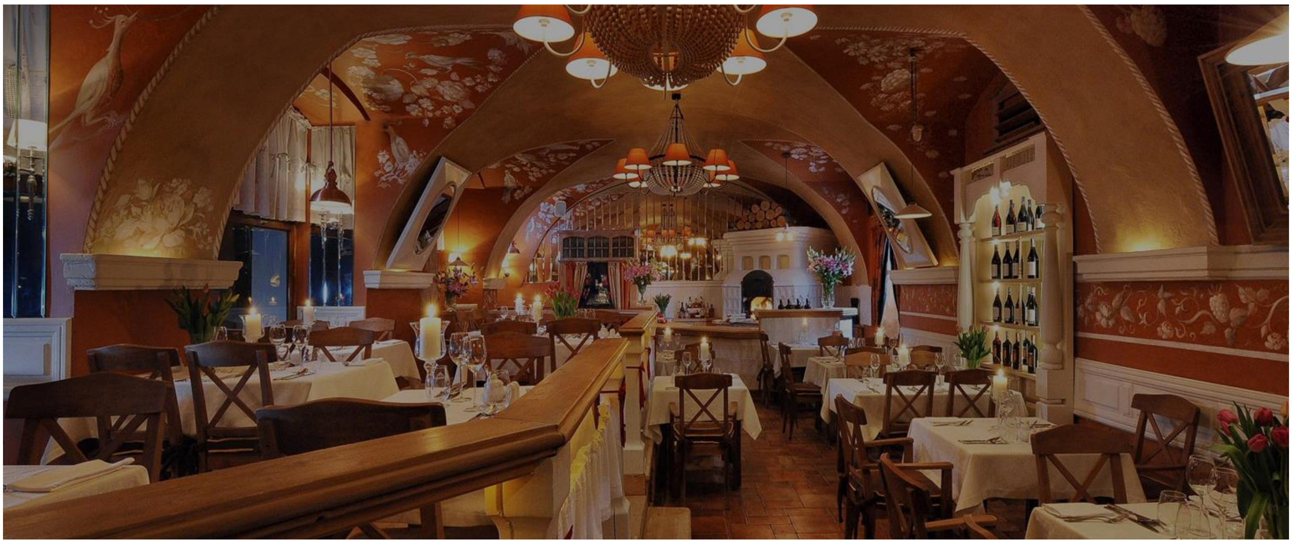
Bi-mineralization occurrence was recognized also in the eastern part of the orefield, close to the Kizhnica andesite quarry. Material for this study came from the contact between andesite and flysh series. Host rock consists of Mg-Fe amphiboles (mainly tremolite), calcite, quartz, potassium feldspar, quartz and apatite as well as ore minerals. Bismuth minerals (native Bi, bismuthinite, galenobismutite and eclarite) are associated with chalcopyrite, pyrrhotite, arsenopyrite, cobaltite, gersdorffite, native Au and form aggregates up to 300 µm dispersed in carbonate zones. Bismuthinite (n_{aik}=2.26-6.06) is the most abundant Bi mineral in the rock and is characterized by homogenous chemical composition. Galenobismutite ($PbBi_2S_4$) occur as separate needle-like form aggregates. Eclarite with ideal formulae $Pb_9Cu_{0.5}Fe^{2+}_{0.5}Bi_{12}S_{28}$ is typical Bi-sulphosalt from Au-rich systems. Eclarite from Kizhnica-Janjevo area is characterized by various chemical composition: Bi - 11.84-12.37 *apfu*, Pb - 9.06-10.17 *apfu*, Cu - 0.01-0.20 *apfu*, Fe - 0-0.64 *apfu*.

References

Buerger R, Giroux G (2016) Technical Report on the Slivovo Gold – Silver Project. Pristina, Kosovo, Avrupa Minerals: 117.

Kołodziejczyk J, Pršek J, Voudouris PCh, Melfos V, (2017) Bi-sulphotellurides associated with Pb−Bi−(Sb±Ag,Cu,Fe) sulphosalts: an example from the Stan Terg deposit in Kosovo. Geol Carpath 68:366–381.

Węgrzynowicz J, Pršek J, Mederski S, Aslani B, Kwiecień K, Kanigowski J (2019) Pb-Bi(-Cu) and Pb-Sb sulfosalts from Stan Terg area, Kosovo. 15th Biennial SGA Meeting, Glasgow, proceedings. vol. 1, 380–383.



Places:

Ice Breaker party – Winne Grono - Czarnowiejska 23, Saturday at 18:00

Food:

1. Gospoda Koko -ul. Gołębia 8
2. Hulaj Dusza – Plac Szczepański 7
3. Chimera – ul. Św. Anny 3 (salad bar)
4. Duży Pokój – ul. Izaaka 3
5. Morskie Oko – Plac Szczepański 8 (traditional food)
6. Zapiekanki na Placu Nowym – Plac Nowy, Kazimierz

(zapiekanka – baguette grilled with mushroom and cheese, usually with variances)

7. Warsztat Cafe – Izaaka 3 (Polish, international &mediterranean food)
8. Warsztat – Miodowa 20 (Polish, international &mediterranean food)
9. Pod Wawelem- ul.Św. Gertrudy 26-29 (nice, traditional style and good meat)
10. Pierogarnia Krakowiacy – Szewska 23 (pierogi – a kind of Polish dumplings)
11. Nowa Prowincja SC – Bracka 3-5 (nice cozy coffeehouse & chocolate)
12. Restauracja Sąsiedzi – Miodowa 25 (Michelin star restaurant)
13. Bałkanica – Czysta 3 (Balkan food)
14. Wedel Chocolate Lounge–RynekGłówny 46(traditional Wedel chocolate)
15. Restauracja Ester – Szeroka 20 (Jewish & Polish cuisine)
16. Stara Zajezdnia -ul. Św. Wawrzyńca 12 (food & beer from their own brewery)
17. Krakowska Manufaktura Czekolady – Szewska 7 (chocolate)

Drinks:

1. Góra Olimp (G-O) – ul. Szymanowskiego 15 (for students and friends of AGH:) beer & pizza)
2. Alchemia– ul. Estery 5 (often live music)
3. Piękny Pies – ul. Bożego Ciała 9
4. C.K. Browar– ul. Podwale 6-7 (mini brewery – non-pasteurised, non-filtered beer brewed according to an old Imperial-Royal Austro-Hungarian recipe :))
5. Pijalnia Piwa i Wódki – ul. Św. Jana 3-5 (beer & vodka)
6. Pijalnia Piwa i Wódki – ul. Szewska 2 (beer & vodka)
7. Omerta– ul. Kupa 3 (over 90 Polish kinds of beer and more)
8. Pauza Club – ul. Floriańska 18 (beer & disco)
9. Stary Port – ul. Straszewskiego 27 (pub for sailors :) but not only)
10. U Jożina – ul. Św. Tomasza 7 (Czech beer)
11. Ambasada Śledzia – ul. Stolarska 8(beer, vodka& herring)
12. Społem – ul. Św. Tomasza 4
13. Pierwszy lokal na Stolarskiej po lewej stronie idąc od Małego Rynku – Stolarska 8 (coffee, beer & snacks)
14. Karlik – Reymonta 17 (students' pub)

Sightseeing propositions in Kraków

1) Wawel Castle

http://www.wawel.krakow.pl/en/

Wawel Hill – a Jurassic limestone rock, a dominant feature in the landscape of Cracow (about 228 m above see level) was formed about 150 million years ago. Situated on the bank of the Vistula river, surrounded by waters and marshes, the hill provided a safe haven for people who have settled here since the Paleolithic Age. It is supposed that the Slav people started living on Wawel hill as early as the 7th century.

2) Etnographic Museum

http://etnomuzeum.eu/

3) Mocak - contenmporary art museum in Krakow

http://en.mocak.pl/

4) Oskar Schindler's Factory

Kraków under Nazi Occupation 1939–1945

http://www.mhk.pl/exhibitions/krakow-under-nazi-occupation-1939-1945

5) Rynek Underground - "Following the traces of European identity of Kraków"

http://www.podziemiarynku.com/index.php?dzial=oszlaku

6) The Old Synagogue

The history and Culture of Jews in Kraków

http://www.mhk.pl/exhibitions/the-history-and-culture-of-jews-in-krakow

7) Hipolit House

The exhibition Bourgeois house shows characteristics of different interiors as they had changed over the centuries. We can be sure that this is the way, former rich citizens of Krakow lived.

http://www.mhk.pl/exhibitions/bourgeois-house

8) Sukiennice museum, Polish XIXthcentruy art

http://en.wikipedia.org/wiki/Sukiennice_Museum

9) National Museum in Krakow

you can see here "Lady with an Ermine" by Leonardo da Vinci

http://www.muzeum.krakow.pl/?L=1

10) Pharmacy Museum

Pharmacy history from medieval times to present.

http://www.muzeumfarmacji.pl/en_opis.php

11) The Eagle Pharmacy

Tadeusz Pankiewicz's pharmacy in Krakow Ghetto

http://www.mhk.pl/exhibitions/13

12) Town hall tower

Market Square

Amazing view on the old city center

http://www.inyourpocket.com/poland/krakow/sightseeing/museums/Town-Hall-Tower_17118v

13) Św.Anny church

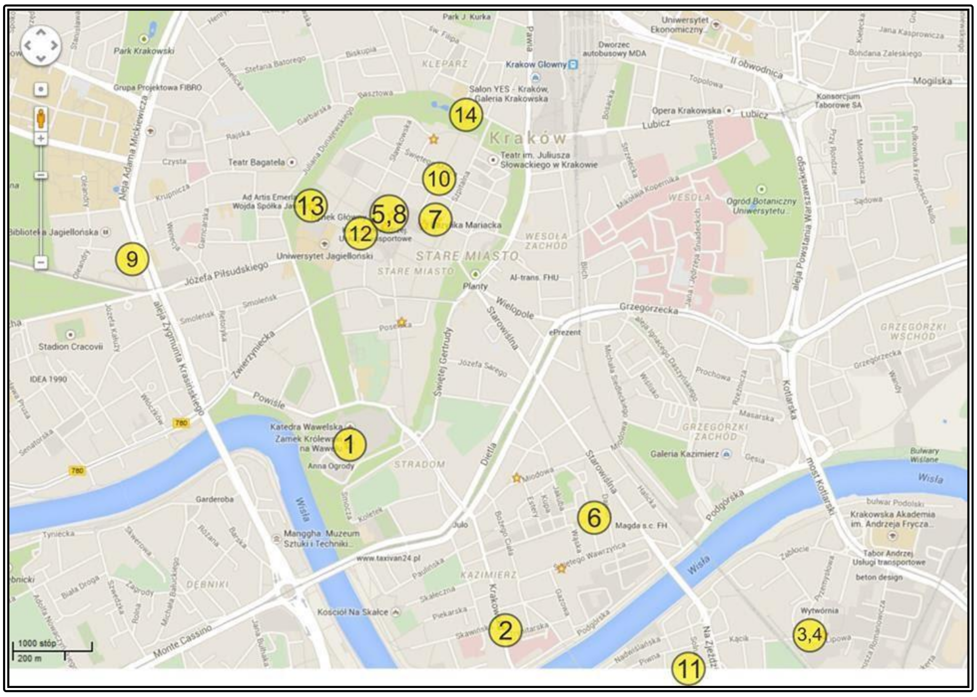
ul.Św.Anny 11

http://kolegiata-anna.pl/z-dziejow-parafii/history-of-the-church-english

14) The Barbican

http://www.mhk.pl/branches/barbican/22

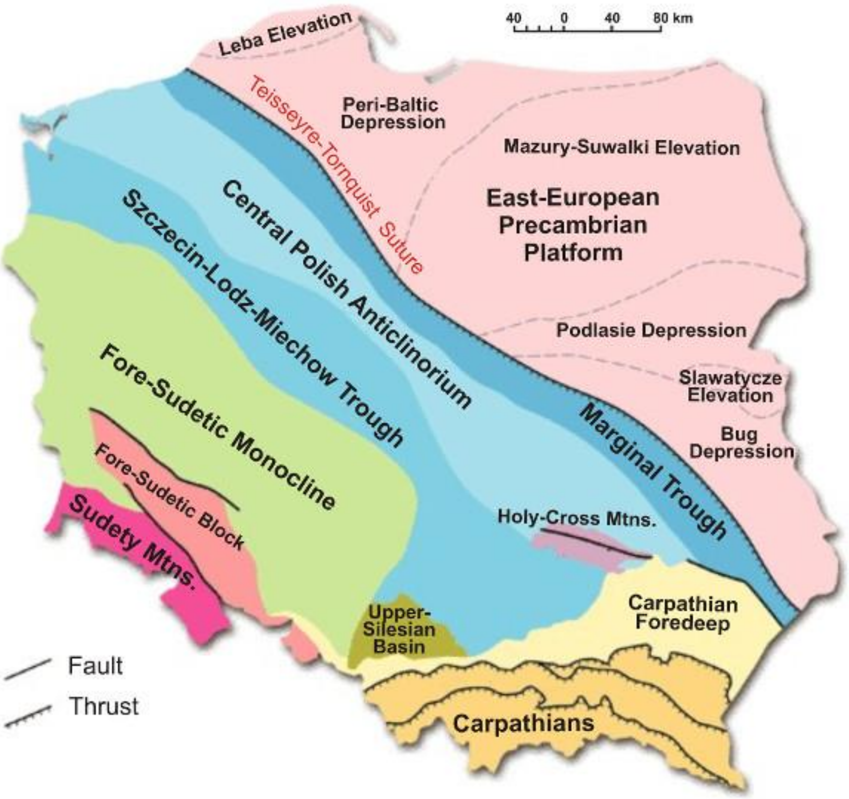
Map of sightseeing locations



Field Trip Guides

Geology of Poland

Poland is located at the junction of three major geological provinces: the northeastern part of the country belongs of the Precambrian East European Platform, the central-western part – to the Paleozoic Platform of Central and Western Europe, and the country's south is occupied by the Carpathians and the Carpathian Foredeep, which belong to the Alpine province (see map below).



Osika, 1990

The Precambrian Platform is composed of a crystalline basement, gently dipping towards the south-west, and of a Phanerozoic platform cover. The Paleozoic Platform consists of consolidated Paleozoic rocks and a Permian-Mesozoic-Cainozoic platform cover. The igneous-metamorphic Sudety Mountains and the Fore-Sudetic Block in the south-west of Poland are part of the Variscan orogen, which is straddling the borders with Germany and the Czech Republic. The Upper-Silesian block to the east consists of a large basin filled with a thick clastic sequence hosting major hard coal deposits. The Holy Cross Mountains are mainly built of Lower- and Middle-Paleozoic clastic and carbonate rocks. Finally, the Carpathian orogen in the south consists of a thrust-and-fold belt of Cretacous and Paleogene flysch rocks.

The bulk of the Polish Lowlands is covered by thick epicontinental Tertiary sediments, which rest on Mesozoic platformal rocks, many of which are carbonates. Continental Pliocene and Miocene deposits occur in the central part of the Tertiary basin, while in the eastern, western, and partly northern parts of the country there are also marine and continental rocks of Paleocene, Eocene, and Oligocene age. The whole of the Polish Lowlands is covered by a thick mantle of Quaternary sediments, related to the multiple glaciation events that affected the region. The thickness of these sand/gravel/till deposits decreases southwards, from over 100m in the north to only several meters in the south.

Compilation made by: redstone-exploration.com/country-profiles/

Wieliczka Salt Mine

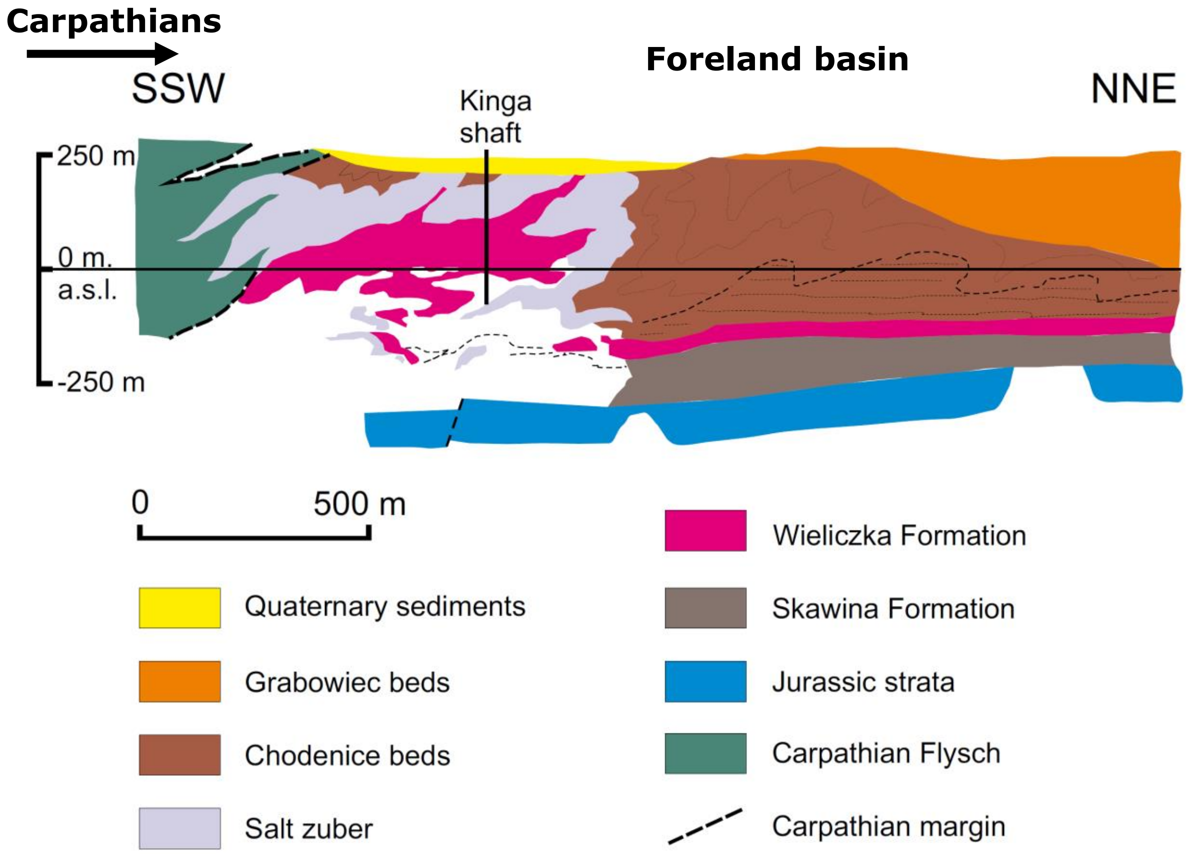
Wieliczka Salt Mine is located in the town of Wieliczka, in Southern Poland, about 15 km from Cracov. The mine is one of the most beautiful places in Poland and since 1978 it has been on the UNESCO's World Cultural and Natural Heritage List [1]. Every year it is visited by over a million tourists [2].

Historic salt mines in Wieliczka and Bochnia are situated by the old trade road from Cracov to the east, in the region well known from salt-making from brines since the Neolithic times. In Bochnia the rock salt was discovered in 1248, whereas in Wieliczka production of the rock salt was confirmed in the town charter in 1290. At the end of the 13th century both mines were united into the Cracow Saltworks. In the 16th century it was the biggest production centre in Poland and one of the biggest in Europe. The rock-salt exploitation ended in Bochnia in 1990 and in Wieliczka in 1996 but magnificent chambers chiselled out in rock salt and amazing underground saline lakes makes them a world-famous tourist attraction. You can take Tourist Route there also parties, concerts, conferences, receptions are organized down there.

The salt deposit in Wieliczka formed in the Miocene Epoch, 13.6 million years ago. The Miocene period saw substantial transformations in the geological structure of the Earth's crust. As a result of colliding tectonic plates new mountain ranges were formed, among them – the Carpathians. In the foreland basin a huge sea was formed and constituted a northern branch of the Tethys Ocean named so in the modern days to honour a character from the Greek mythology – Thetys, a wife to Titan Okeanos. Various types of rock sedimented in the reservoir, with rock salt layers among them [2].

Salt deposits formed in many parts of this huge reservoir. Deposit formation processes were connected with cyclical changes of the water level and shoreline as well as submarine landslides and flows occurring in parallel. The reservoir also received varied amounts of terrigenous material – claystone, silt, and sand [2].

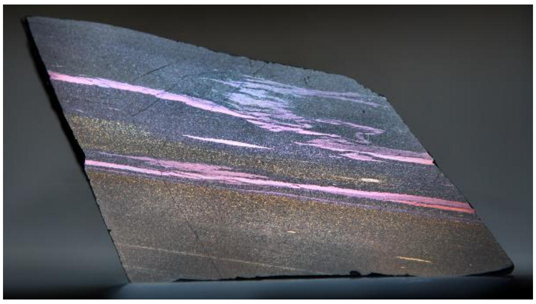
The Wieliczka deposit consists of the upper boulder deposit and the lower stratiform one. The boulder deposit was formed as a result of submarine flows in southern part of the evaporate basin.The Wieliczka deposit owes its final shape to the orogeny and overthrust movements of the Outer Carpathians which resulted in accumulation of salt deposits causing a several-fold increase in their original thickness. Additionally they were elevated to the surface thanks to which, millions years later, exploitation of the deposits could be started easily[2].



[1] whc.unesco.org

[2] www.wieliczka-saltmine.com

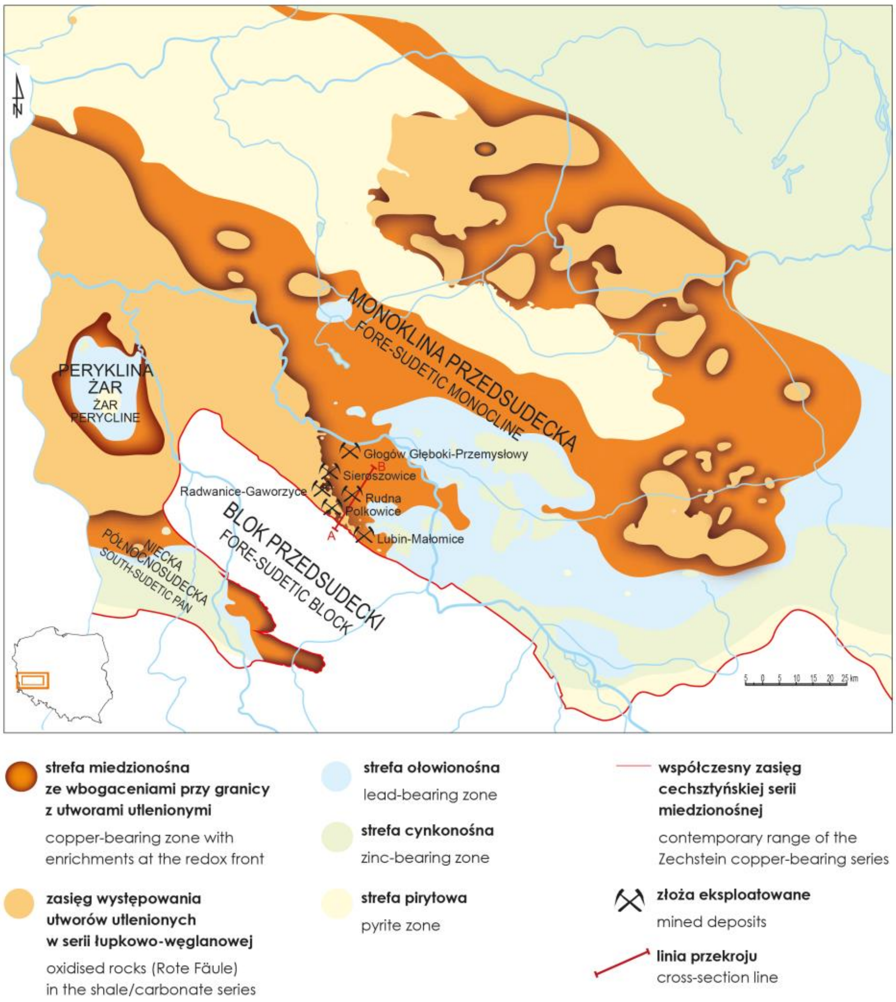
Kupferschiefer



Poland's largest accumulations of copper and silver are associated with Sudetic deposits that are found in the Fore-Sudetic Monocline (New Copper Basin) and in the North Sudetic Trough (Old Copper Basin). The deposits are composed of Weissliegend sandstones, Basal Limestone, Kupferschiefer shale and Zechstein limestone. The deposits are polymetallic: the value of the silver present in the deposits is almost equal to the value of copper, with significant amounts of lead, zinc, cobalt, molybdenum, nickel, selenium, rhenium, gold and platinum.

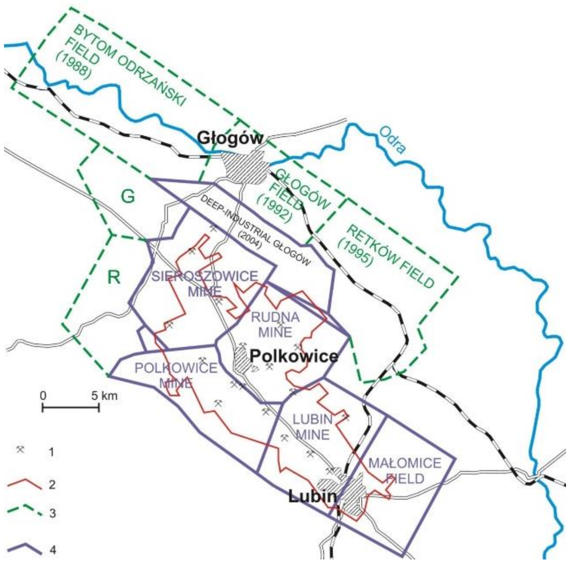
The developed and currently mined deposits are: Rudna, Sieroszowice, Polkowice, Lubin-Małomice, Głogów Głęboki-Przemysłowy and Radwanice-Gaworzyce in Radwanice Wschodnie region. All of the aforementioned deposits are located in the Fore-Sudetic Monocline. They are all belonging to the KGHM Polska Miedź S.A company. In 2018 anticipated economic resources of copper ore in the areas of the Fore-Sudetic Monocline and the North Sudetic Basin amounted to 1,905.65 million tonnes yielding 34.04 million tonnes of metallic copper and 103.28 thousand tonnes of silver.

The first clear signs of the rich copper ores in this area were found in 1957, in the borehole Sieroszowice IG-1, at depths of 601.20–603.5 m. However, the presence of metal-bearing black shale ("Kupferschiefer") in the Fore-Sudetic Monocline had been recognized a few years earlier. Prospecting and documenting the copper ore reserves were supervised by Jan Wyżykowski from the Polish Geological Institute. The first documentation, based on 24 boreholes was completed in 1959. On 20th March, 1963, the first copper ore was extracted from the "Boleslaw" shaft of the Lubin Mine in the eastern part of the copper district. Now, there are three mines: Lubin, Polkowice-Sieroszowice and Rudna. For organizational reasons, they all are connected underground and form one of the biggest underground mine systems in the world.



MAPA ROZMIESZCZENIA ZŁÓŻ RUD MIEDZI I SREBRA W POLSCE (WG S. OSZCZEPALSKI I IN., 2016)
MAP OF COPPER AND SILVER ORE DEPOSITS IN POLAND (COMPILED BY S. OSZCZEPALSKI ET AL., 2016)

(MINERAL RESOURCES OF POLAND AS SEEN BY POLISH GEOLOGICAL SURVEY – Copper & Silver, POLISH GEOLOGICAL INSTITUTE - NATIONAL RESEARCH INSTITUTE 2018)



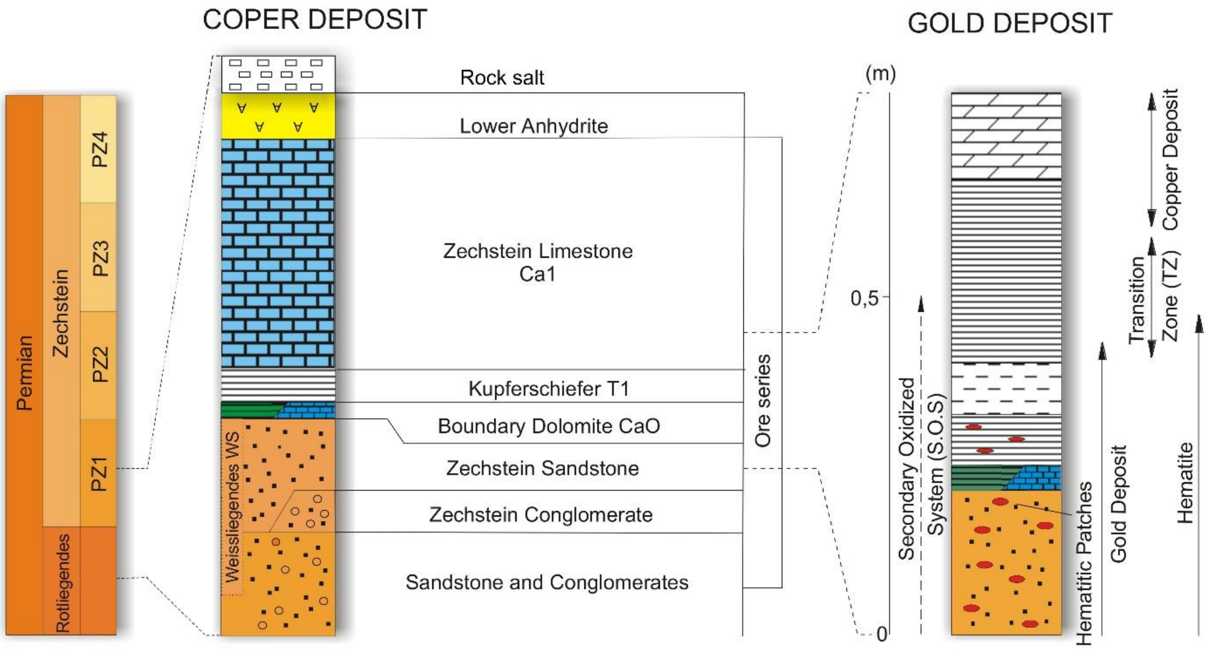
Lubin-Sieroszowice mining field with reserve areas (after Leszczyński 2011). 1-shafts, 2- mining operations, 3- potential areas, 4- mining licenses, G- Gaworzyce, R- Radwanice

Geological setting

The Legnica-Glogów Copper Belt area is situated in a southern marginal part of the ForeSudetic Monocline. In general, the stratigraphy incorporates three main units: a metamorphosed Proterozoic-Palaeozoic basement, a Permo-Triassic sedimentary succession, which is gently dipping to the northeast, and thick, overlying, sub-horizontal Caenozoic sediments above

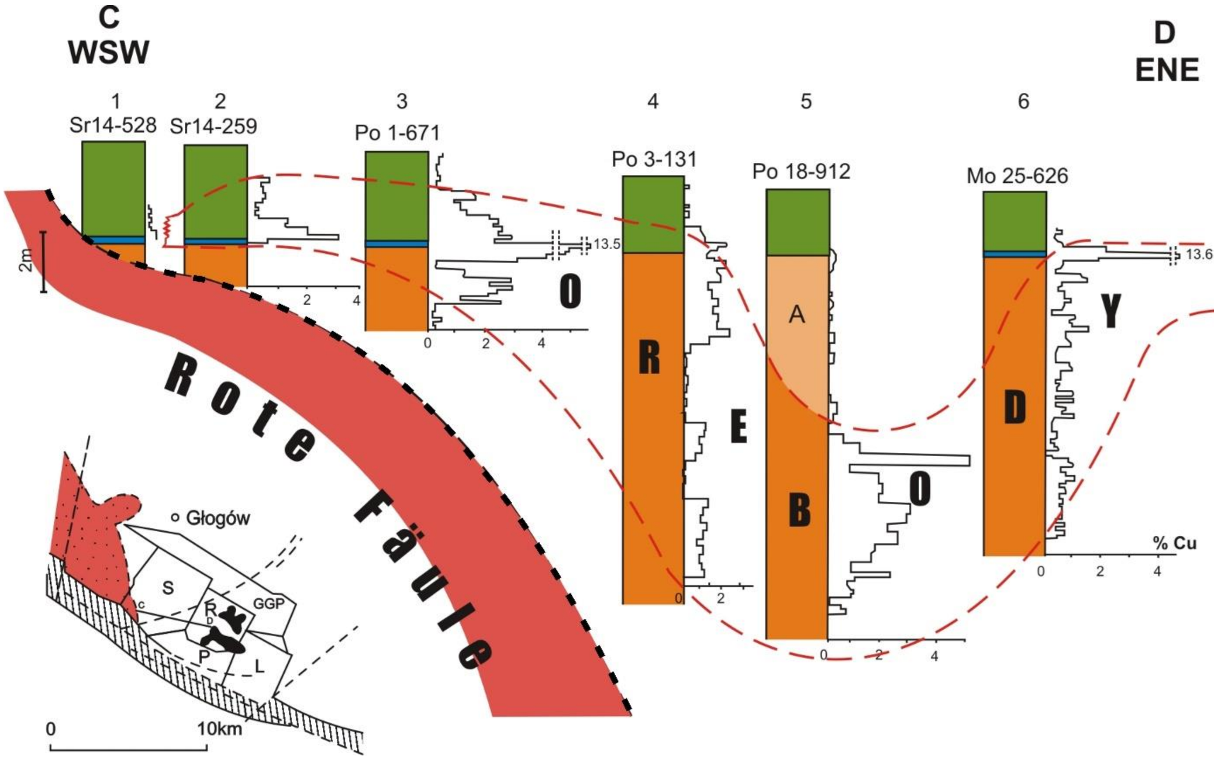
The Permo-Triassic succession, a part of which hosts copper mineralization, begins with two reddish-brown conglomerate-sandstone-mudstone sequences of early Permian age, totalling up to 150 m in thickness. These sediments are covered by rhyolites and trachybasalts of variable thickness, which, in turn, are overlain by red quartz sandstones of late Lower Permian age. Due to pervasive hematite and goethite staining, the whole Lower Permian suite is termed the Red Footwall Sandstone (Rotliegendes). Within the mining area, the thickness of this unit is in the range of 230 m to 300 m. The uppermost part of this succession (from less than a metre to over 40 m in thickness) lacks hematite and goethite and consists of fine grained white sandstones with kaolin, carbonate, clay or anhydrite cement. Because of its colour, this unit is termed the White Footwall Sandstone (Weissliegendes). The colour transition is irregular, suggesting that the white sandstone probably represents the Rotliegendes reworked during the Zechstein transgression.

The Lower Permian rocks are conformably overlain by four Upper Permian evaporitic cyclotherms and by Triassic red beds and carbonates. The Upper Permian sequence generally begins with a very thin bed of grey micritic dolomite, termed the Boundary Dolomite, which is then followed by black fissile shale carrying copper sulphides and hence called Cupriferous Shale (Kupferschiefer). Its thickness typically varies between 30 cm and 50 cm. Normally, the Cupriferous Shale grades upwards into dolomites and limestones up to 80 m in thickness, collectively referred to as the Basal Limestone or Basal Dolomite. However, the Cupriferous Shale is missing along several northwest-trending elevations of the White Footwall Sandstone floor, and the sandstones along these elevations are directly overlain by limestones and dolomites. The Cupriferous Shale passes laterally westwards into a red shale horizon without copper sulphides. This is an oxide facies known as the Red Spotted Facies (Rote Fäule). The Upper Zechstein sequence in the mining district ends with thick evaporates (anhydrite and halite).



Stratigraphic column through typical section in the Lubin-Głogów district. The copper deposit (modified after Oszczepalski, 1999) and a section showing the gold deposit (after Pieczonka & Piestrzyński, 2001).

Copper mineralization occurs in the uppermost part of the White Sandstone and in the lowest Zechstein units, including the Boundary Dolomite, Cupriferous Shale and the lowermost part of the overlying dolomites. Because its vertical extent does not coincide with stratigraphic boundaries, the mineralization can be best described as stratabound. The ore is divided into sandstone ore, shale ore and carbonate ore and, for practical reasons, the last two types are grouped together as shale-carbonate ore. The thickness of the deposits varies from 1 up to 26 meters. Economic parameters for the deposit are: 50 kg/m2 of Cu, and minimum content of 1.7 % copper in the interval of extracted wall. Cut of grade for the copper ores is 0.7% Cu. One gram of silver is an equivalent for the 0.01 % of copper content in the ore.



Stratigraphic columns through the Kupferschiefer in the Sieroszowice (1 and 2) and Rudna (3, 4, 5 and 6) mines, showing rock type (green-Zechstein limestone, blue-Kupferschiefer shale, orange-Rotliegend sandstone, A-anhydrite cement) and histograms of copper content and the relation of mineralization to the Rote Faule alteration facies (Wodzicki & Piestrzyński, 1994).

Mineralization

Over 140 ore minerals have already been identified within the copper district. Chalcocite is the dominant ore mineral and locally can constitute up to 90 vol.% of the rock. The copper ores are also characterized by significant amount of bornite, chalcopyrite, digenite, covellite, galena, sphalerite, pyrite, tennantite and tetrahedrite. Ore minerals have usually xenomorphic shapes. In the mining district the following types of ore mineralization can be distinguished: dispersed, nests, lenses, ore bands, veinlets and veins, and massive.

Dispersed mineralization dominates in all types of ores: sandstones, shales, and carbonates. It can be found in all stages of mineralization processes, being the most important during the early stages. Pyrite, chalcocite cobaltite and bornite framboids are common here.

Nest-type mineralization is very common in carbonates ores, and rare in the sandstone. Nest are composed of copper sulfides, carbonates and sulfates in the ore horizon. In the sub-grade ores sphalerite, galena, pyrite, marcasite also occur. This structure are well visible macroscopically.

Lensoidal structures are common in shale and carbonate ores. Ore minerals often replace organic remnants of brachiopoda, foraminifera and ostracoda. Sulfides pseudomorphs after lensoidal francolite are also observed in the shale horizon.

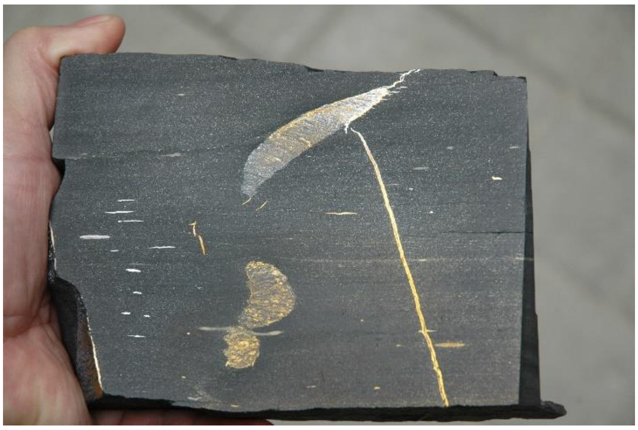
Ore bands are observed only in the sandstone ores. Ore bands occur about 1 meter below the Kupferschiefer, and usually are developed parallel to the top of the sandstone strata. Number of ore bands depends on the place and can reach 60. Ore bands or rhythmites are very regular in the shape.

Massive mineralization structures are typical for the sandstone ore. This structures are classified as late diagenetic They can be observed in the uppermost part of the Weissliegende and in the contact zones with the anhydrite-cemented sandstone. Locally chalcocite replaces all constituents of sandstone forming massive copper ore containing up to 70 wt. % of Cu. Massive structures of ore minerals, mostly chalcocite, are also observed in the boundary dolomite. No spatial relationship to the vein-type mineralization is observed.

Veins and veinlets are very common in the shale horizon, and sometimes in the clayey dolomite. Veinlets (up to 1 cm thick) are typical for the shale and developed both parallel and diagonal to the shale lamination. They are composed exclusively of base metal sulfides.

Veins (up to 1.2 meter wide, usually 5 – 15 cm) are rare and occur in dolomite and sandstone. They are composed of gangue and sulfide minerals in different proportions. These structures represent late stages of mineralization, probably associated with Alpine tectonism. Some veins contain Ni, Co, Ag, U minerals (Rűcken type). This style of mineralization is not of economic importance.

A



B

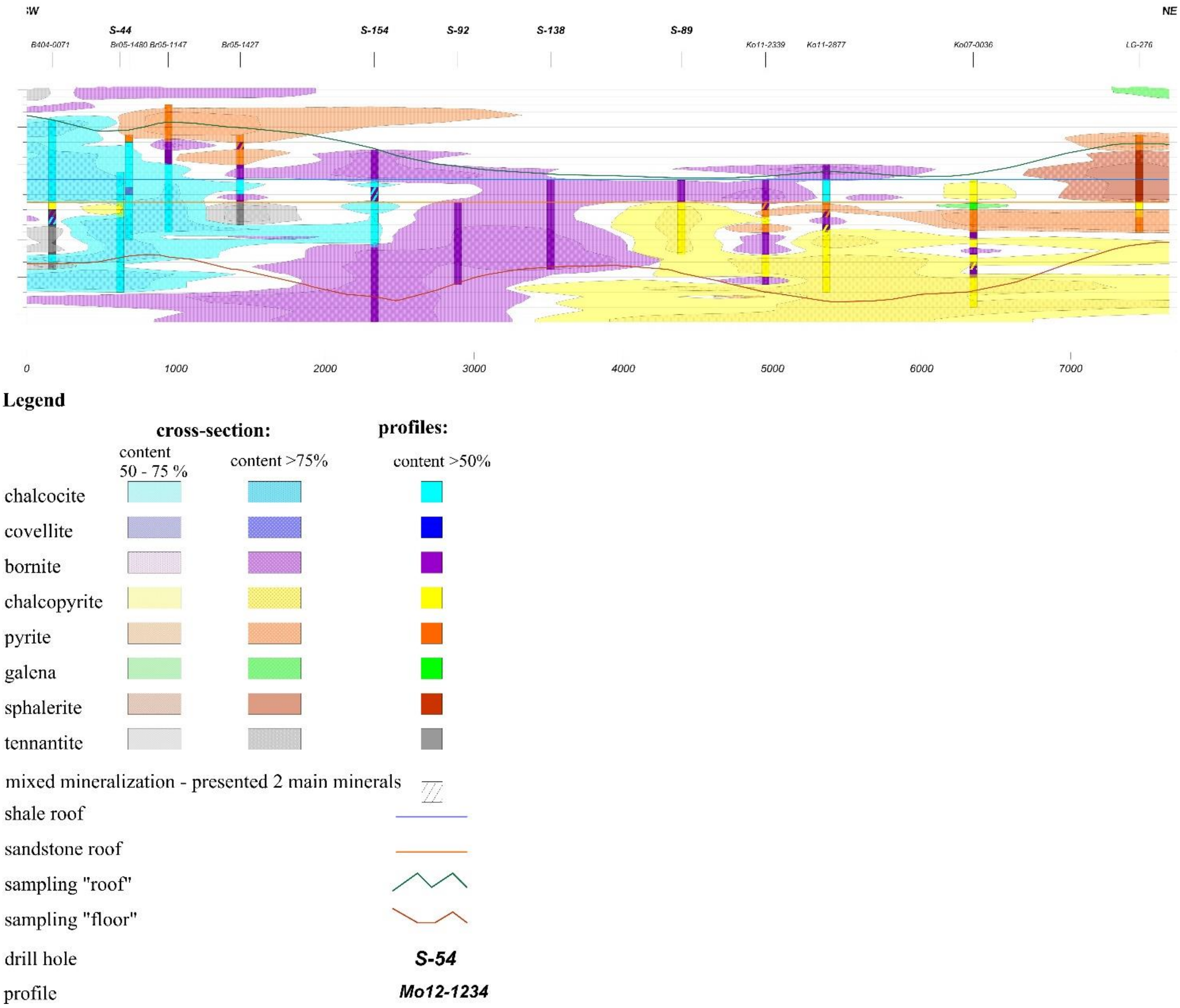
C

D

Ore mineralization in shales. A: bornite veinlet in shale; B: chalcopyrite mineralization in organogenic structures, forms are one of the proves for non-sedimentary deposit origin; C: effect of pressure solution of calcareous shale and dolomitization; D: section through the red (secondary oxidized) and transition (grey) zones of the Kupferschiefer beds, Polkowice West Mine.

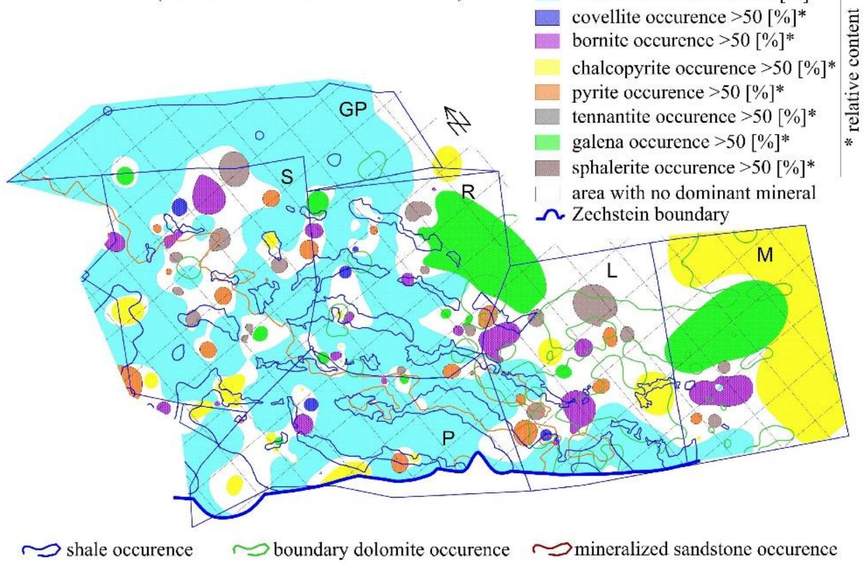
Mineral zonation

In the mine scale only a vertical type of zonation is observed. Idealized mineral distribution is (from the bottom to the top): pyrite - chalcopyrite – bornite – chalcocite bornite – chalcopyrite - galena - sphalerite – pyrite. Very often the specific zones overlap (see Fig. 21). In the horizontal scale the zonation has the same characteristic (see maps below, after Pieczonka 2011).

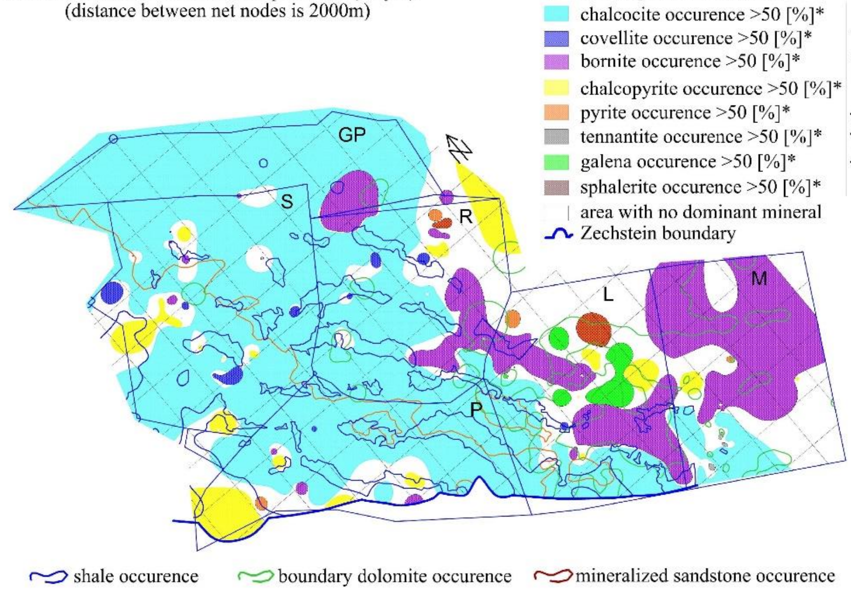


Vertical distribution of ore minerals (after Pieczonka, 2011).

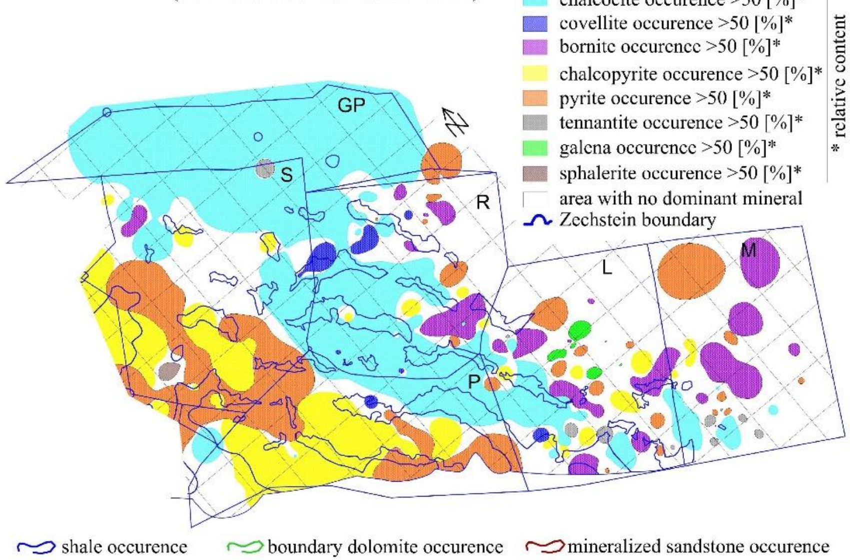
Main ore minerals distribution map in dolomite (I layer)
(distance between net nodes is 2000m)



Main ore minerals distribution map in shale (I layer)
(distance between net nodes is 2000m)



Main ore minerals distribution map in sandstone (I layer)
(distance between net nodes is 2000m)



Gold bearing mineralization (gold mineralization located 0-0.5 meter below the copper-silver orebody)

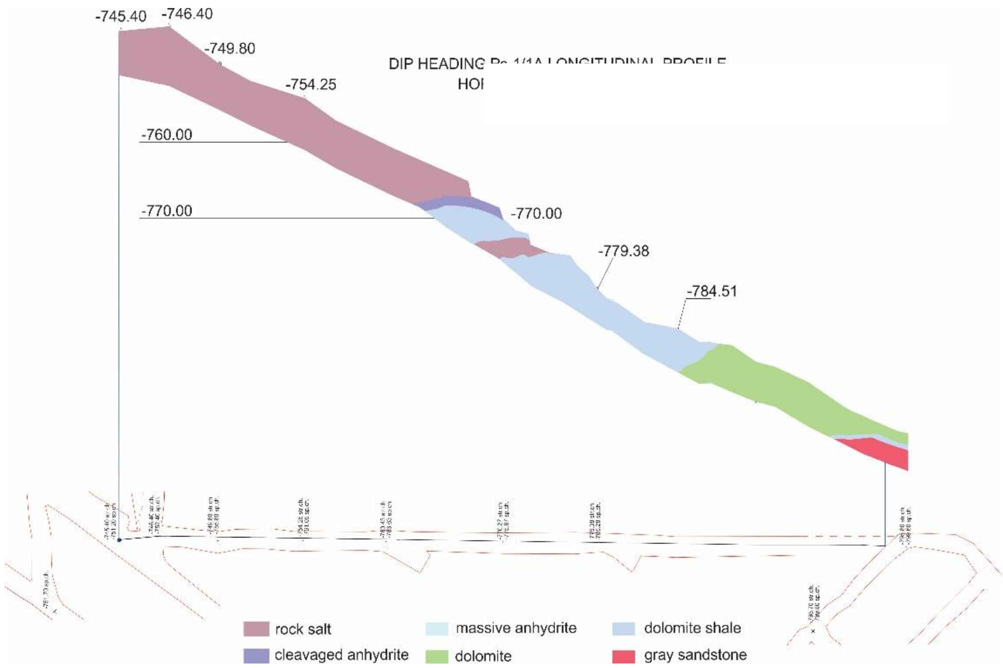
Current studies in the Polkowice-Sieroszowice Mine show that two oxidation stages can be recognized:

- Rote Fäule "facies", represented by a diagenetic oxidation stage (DOS). Rote Fäule is characterized by fine-grained, dispersed hematite.
- secondary oxidation stage (SOS) that overprints the DOS. It is characterized by maroon patches and laminae, and is peneconcordant relative to the Rote Fäule and the deposit lithologies. There is a strong relationship between SOS and noble metals occurrences.

Gold content ranges from 0.5 up to 106 ppm, with an average of 0.717 – 3.49 ppm, depending on the counting block. Peneconcordant gold-bearing horizon is characterized by the presence of high fineness native gold, electrum, hematite, and minor: pyrite, chalcopyrite, digenite, chalcocite, covellite, rammelsbergite, clausthalite and tetraauricupride.

Rock salt deposit

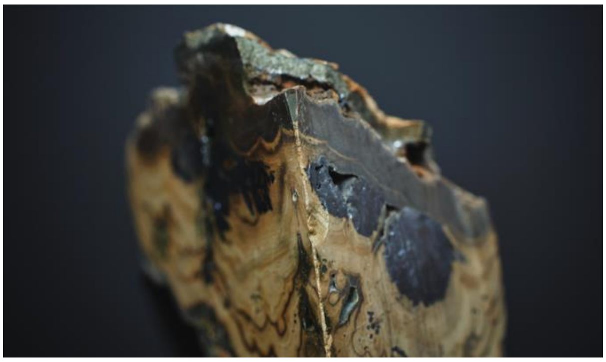
The Oldest Halite unit in the mining area of Sieroszowice occurs under about 1 km-thick cover of Younger Zechstein, Mesozoic and Cenozoic sediments. It is underlain by the Lower Anhydrite and overlain by the Upper Anhydrite units. The top of the Oldest Halite is more planar in comparison to its bottom, which results in thickness variation of the salt unit in the range of 0–186 m. The thickness variation seems to be controlled by faults occurring in the basement (see: Kijewski, Salski 1978), as both the thickest and thinnest accumulation of salt is observed in the vicinity of evidenced or presumed basement faults. Rock salt constituting the Oldest Halite unit (Na1) is heterogeneous. It varies from pure, transparent rock salt with subtle layering, through distinctly layered, to grey and dark grey rock salt. Locally it contains considerable admixture of anhydrite either dispersed in rock salt or occurring in blocks of varying size, ranging from millimeters to tens of meters. Internal deformation of salt was pointed already in early works on the salt unit structure (Szybist 1976; Kijewski, Salski 1978).



Dip heading Ps-1/1A longitudinal profile, Sieroszowice Mine (after Wrzosek, OZG Polkowice-Sieroszowice).

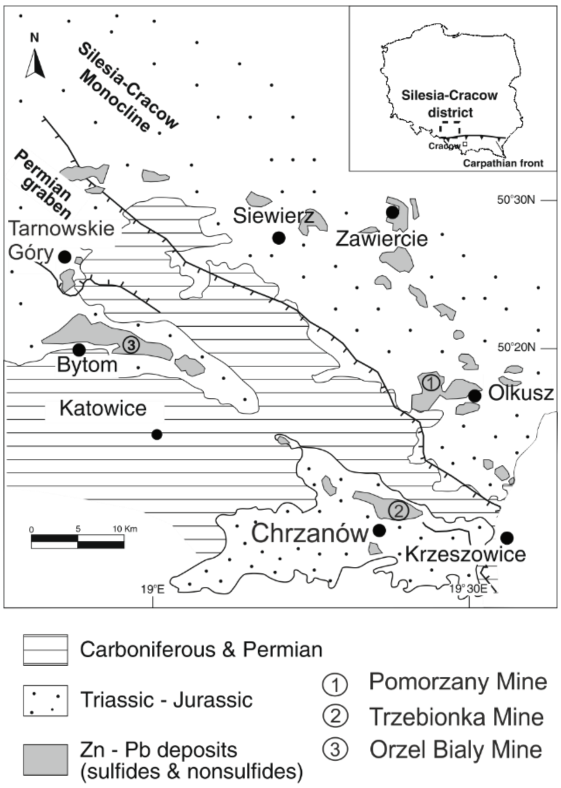
FOT. / PHOTO BY: ZAKŁADY GÓRNICZO-HUTNICZE „BOLESŁAW" S.A.

Pomorzany mine



Poland is a traditional producer and exporter of zinc, and in the early years of the 20th century the Zn-Pb industry in the Silesia-Cracow region was one of the largest in the world. Mining for lead, silver, and iron began in the 12th century and, by the 18th century, zinc had become an important commodity. Early production focused on the oxide ores but during the last 50 years, production has been entirely from sulfides. Mining activity started in several ore fields around the towns of Bytom, Tarnowskie Gory, Siewierz, Chrzanow, and Olkusz. Although the historical production in the district is not accurately known, estimates reported in 2004 of production by the ZGH Boleslaw company alone from 1945 to 2003 are put at 110.6Mt. Also by-product silver, cadmium, thallium, gallium and germanium have been recovered.
Four main clusters of mineral deposits are recognized in the district:

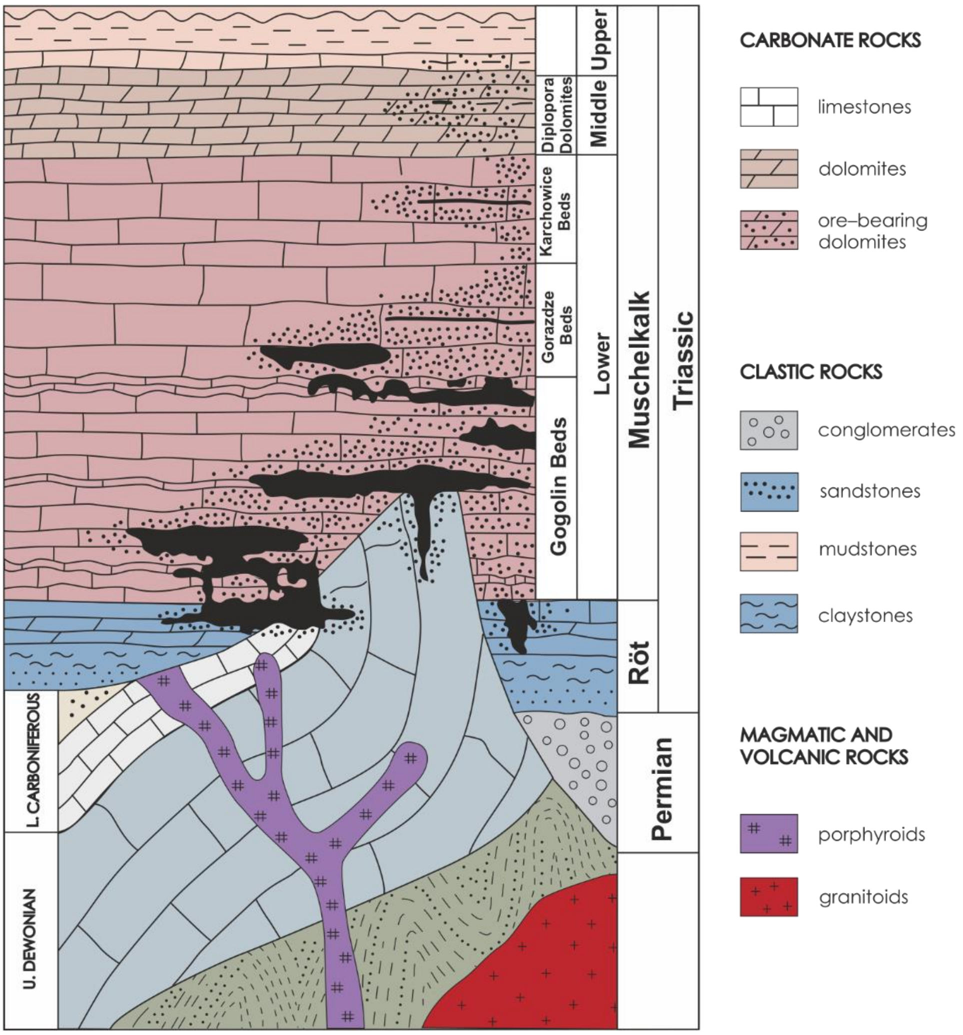
1) Olkusz-Pomorzany area; last active mine
2) Trzebinia area with closed Trzebionka mine;
3) Bytom area in which the mines are closed;
4) The undeveloped deposits at Zawiercie-Kalety, including Rokitno.



Anticipated economic resources of Zn-Pb ores as of 31.12.2018 amounted to 83.96 million tonnes of ore yielding 3.59 million tonnes of zinc and 1.41 million tonnes of lead. Active mining in the district is currently restricted to the Olkusz area (Pomorzany mine) operated by a State-owned company, ZGH Boleslaw. In 2018, Polish mines extracted 1,594 thousand tonnes of ores yielding 43 thousand tonnes of zinc and 13 thousand tonnes of lead. Historically, the Silesian-Cracow region is regarded as one of the world's largest area of Zn-Pb deposits occurrence of the so-called Mississippi Valley-type deposits (MVT) and after 800 years of continuous mining, still produces zinc and lead.

Regional Geological Setting

Economic zinc and lead ores of the Upper Silesia district are hosted by dolomites of the Middle Triassic Muschelkalk Formation that overlie the boundary between the Caledonian Krakow-Myszkow structural zone and the Varisican Upper Silesian coal basin. South of the ore district, the Triassic rocks are overlain by Miocene molasse and flysch of the Carpathian foredeep deposited during Alpine orogenic phases in the Cretaceous to Tertiary periods. One of the most important ore controls for the district is faults and fractures in the Mesozoic rocks that mainly reflect reactivation of faults and fractures in the structurally complex basement.



Generalized geological profile of the ore series in the Silesia-Cracow region.

The oldest rocks that host ores in the district are medium- to fine-grained Devonian limestone and dolomite. Below these rocks are Lower Palaeozoic sedimentary, metamorphic, and igneous rocks that comprise the Varisican-Caledonian basement. The first sediments deposited on top of the Palaeozoic basement rocks consist of locally well-developed red sandstone and up to 50m of argillaceous dolomite and gypsum-bearing beds of the Buntsandstein Formation. Overlying the Buntsandstein is the Middle Triassic Muschelkalk Formation, the most important host for mineralization. The Muschelkalk Formation consists of mostly limestone and lesser amounts of diagenetic dolomite, claystone, and sandstone that total about 300 to 400m in thickness. Following deposition of the Muschelkalk, erosion produced a paleokarst network in the Muschelkalk that is believed to have played an important role for pre-mineralization ground preparation.

The Ore-Bearing Dolomite ('OBD') is mainly contained within the Lower Muschelkalk Formation and was formed after deposition of the Lower Muschelkalk Formation but before Jurassic sedimentation. However, OBD is also present in Devonian carbonates and extends into the Middle-Upper Muschelkalk.

Stratigraphic Setting

It is estimated that 95% of the ore produced in the Silesia district has been from the 35-70m thick OBD of the Muschelkalk Formation. Undeveloped mineral deposits are located in the areas of Klucze, Zawiercie, Rokitno and Olkusz. Zinc and lead mineralization occurs in Devonian through Jurassic rocks and trace occurrences are present in Cretaceous and Tertiary rocks. The deposits are broadly stratiform, with one or more mineralized horizons present, but the bulk of mineralization is typically hosted by the lower horizon of the Muschelkalk Formation, at the contact between the dolomite and underlying limestone. About 4% of the estimated remaining ore reserves in currently operating mines in the district are hosted in Devonian carbonates.

The most important ore horizons in the Muschelkalk Formation are the Gogolin Beds, Gorazdze Beds, and Karchowice Beds. Other ore-bearing horizons include the Röt Formation of Lower Triassic, Diplopora Dolomite of the Middle Muschelkalk, and the Tarnowice and Boruszowice beds of Upper Triassic. Minor mineralization is present in the Keuper (Upper Triassic) Formations and in Permian rocks.

Mineralogy

Sphalerite, galena, marcasite, pyrite with minor amounts of sparry dolomite, lesser amounts of calcite, and trace amounts of barite comprise the major mineral assemblage of the ores. In addition, cadmium, germanium, gallium and thallium are reported as trace elements – relatively small quantities of these elements are recorded. Average silver values for the ores of the district are reported as 24g/t, but those for the Boleslaw and Olkusz deposits are recorded as 14g/t and 12g/t Ag respectively.

Sphalerite: Minor amounts of sphalerite occur as small, individual or aggregate grains, referred to as granular sphalerite. Generally, sphalerite occurs as banded or spherulitic aggregates of colloform sphalerite or as dark bands consisting of small grains or fibrous aggregates of crystals (schalenblende). An unusual form of sphalerite, called brunckite, occurs as <15 micron-diameter particles forming unconsolidated accumulations in some mineralized cavities, fractures, and fault zones.

Galena: Morphologies of galena range from colloidal-size particles included in colloform sphalerite to bands several centimetres wide to well-developed crystals as large as 3cm in diameter. Both cube-octahedral and cubic forms are present in the district.

Iron sulfides: Iron sulfides occur as dominantly pyrite early in the paragenesis, whereas later stages are typically mixtures of marcasite and pyrite. The earliest iron sulfide occurs as disseminated small grains of pyrite with traces of marcasite included in sparry dolomite cement and granular sphalerite or as discrete bands of early pyrite. In colloform and dark banded sphalerite, small grains of pyrite and marcasite are present as inclusions but more commonly, iron sulfide forms discrete bands. Late stage iron sulfides form botryoidal masses of marcasite and pyrite.

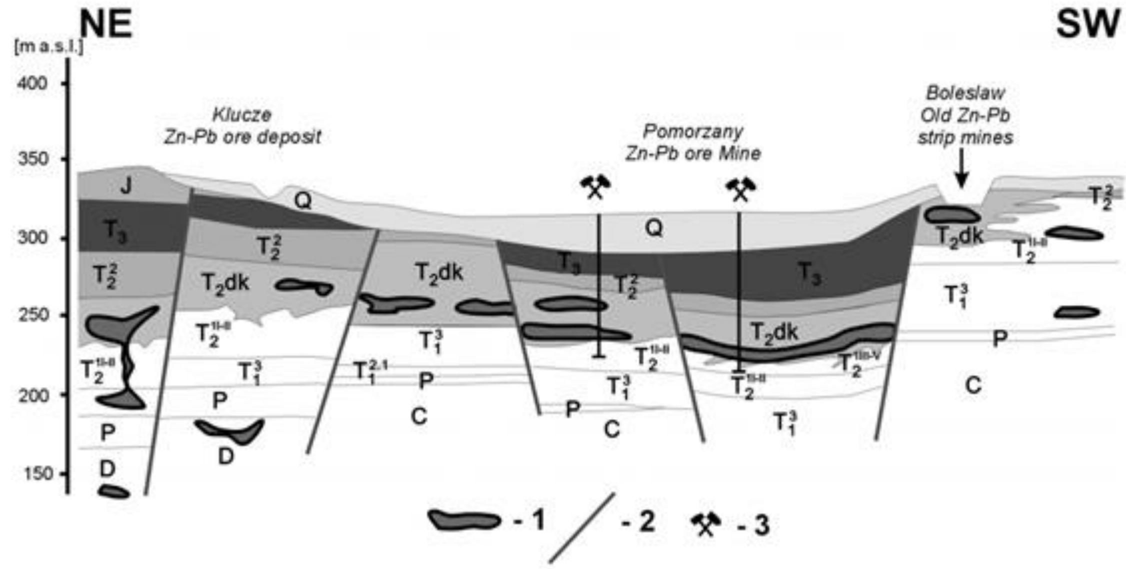


Figure 5. Typical cross section through the Pomorzany mine (after Cabala 2004).
1-Zn-Pb ore, 2- faults, 3- shafts