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WP7 Historic Mine Sites revisited

Case Study

The Kutná Hora Ore District, Czech Republic

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1 Introduction

The Kutná Hora Ag-Pb-Zn-In (Bi, Cd) ore district (60 km to the east of Prague, Central Bohemia, Czech Republic) represents a hydrothermal vein type mineralization of Variscan age (Holub et al. 1982). Bernard (1996) classifies the ore district as k-pol deposit formation (sulphidic polymetallic mineralisation of younger Variscan age). This classification is based on mineral associations, similar to the Freiberg ore district in Saxony or Havlíčkův Brod ore district in the Western Moravia. More than 180 minerals were described from the Kutná Hora ore district, many of them are unique for this locality.

The beginning of silver mining in the Kutná Hora ore district is probably connected with the mint of Slavník dynasty that was run in the nearby village Malín in the end of the 10th century. The real expansion of exploitation started in the second half of the 13th century, probably due to contributions of Cistercians from the monastery in Sedlec (part of the Kutná Hora). In the beginning of the 14th century, Kutná Hora (called Mons or Chuttis) represented one of the largest mining town in the Europe with advanced organization and technology. Mining boom in the Kutná Hora ore district was reflected in a significant improvement of an economic and power position of the Czech Kingdom and also led to a declaration of an important legal document, the Mining Law – *Ius regale montanorum* (around 1300), and establishment of the royal mint where the famous Prague groschens were minted.

The last development of exploitation in the mining district started after establishment of the German administration in 1939 just at the beginning of the World War II. Exploitation of polymetallic ores, especially Zn and Pb, started in the northern part of the ore district at the Turkaňk mine on the suburbs of the town. Simultaneously with production of Turkaňk mine, a mineral exploration, field investigation and test borings of the whole mining area were carried out (especially in the northern part and area under Cretaceous sedimentary cover) with variable intensity during second half of the 20th century. Turkaňk mine, state enterprise, was finally closed in 1992, because production was no longer economic.

Today remnants of mining activities are represented by accessible rests of a mining dumps from an older mining era containing ore minerals and by a rehabilitated tailings pond. Perspective areas in the northeastern part of the ore district under the Cretaceous sedimentary cover were indicated by geophysical investigation in the eighties and should be covered by the prognostic area.

Contaminated mining water is nowadays processed at the cleaning facility located at the place of the former mineral processing plant. The historical mining left many risks in a form of collapsed mine works in the historical town and surrounding villages. These problems are investigated by studying of a historical documentation and field investigation of historical mining works by



Historical Mining Department of the Czech Geological Survey in Kutná Hora as well as by private companies and voluntary organizations.

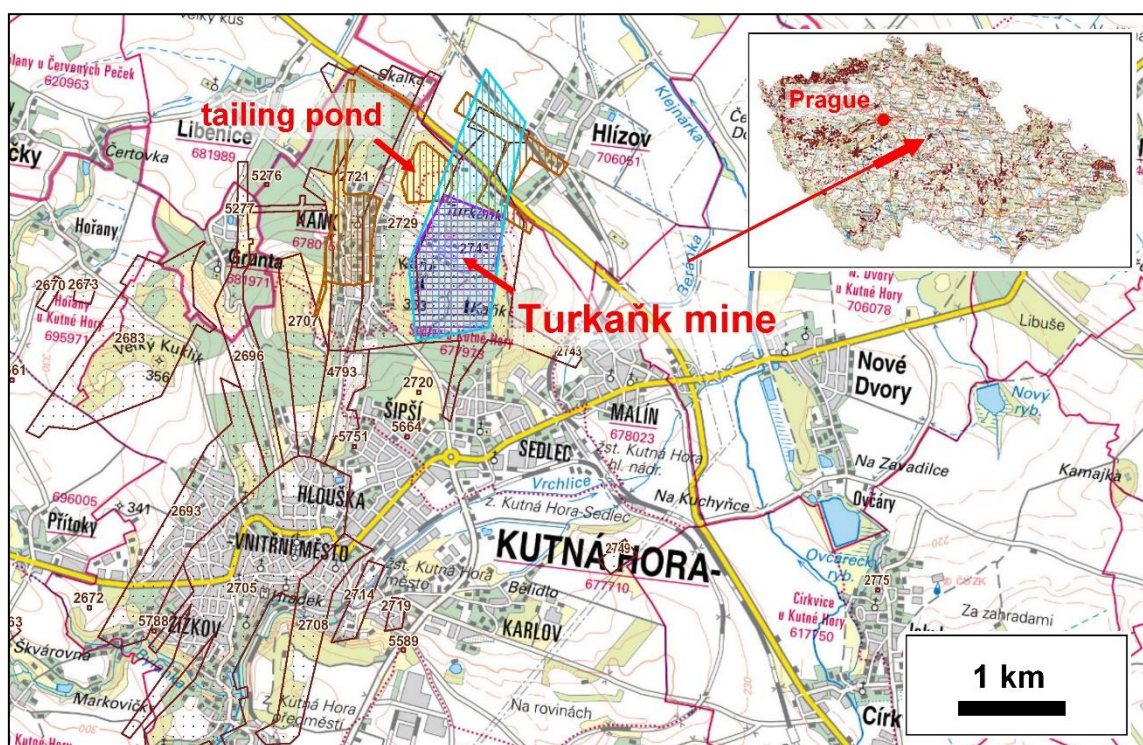


Figure 1: Situation of Kutná Hora ore district with undermined areas, location of Turkaňk mine and rehabilitated tailing pond. <https://mapy.geology.cz/>

2 Geological Setting

2.1 Regional geology

The Kutná Hora ore district is situated in the central part of the Bohemian Massif in the Kutná Hora-Svratka crystalline complex (Chlupáč 1994), directly in the subregion of the Kutná Hora unit that submerges beneath the sediments of the Cretaceous Basin in the North. Other cover units are built of Tertiary and Quaternary sediments.

The main features of this unit are lower grade metamorphism, the primary metamorphic lithology and absence of Variscan granitoid massifs, although the Variscan Central Moldanubian Pluton played a significant role in the ore forming processes. Host rocks of the mineralised veins are migmatites and two types of gneisses with rare amphibolites. The mineralisation event took place in the lower Permian (Bernard 1996). The axial part of the Central Moldanubian Pluton was



uplifted during the final phase of the intrusion and at the same time a system of fissures was formed in the Kutná Hora ore district. Transition from anticlines to synclines are typical structural features of the ore district (Holub et al. 1982). Lamprophyres and isolated granodiorite porphyries penetrated along the tension structures of this system. In the same field of stress, tourmaline (sometimes with cassiterite) and quartz veins and veinlets formed (Losert 1968). After a stress release in the axial part of the dome, it subsided, and the older system of fissures then probably served as supply channels for hydrothermal fluids. Mineralization mainly took place in the section with brecciated structures near the boundaries between the gneiss and the migmatite complexes.

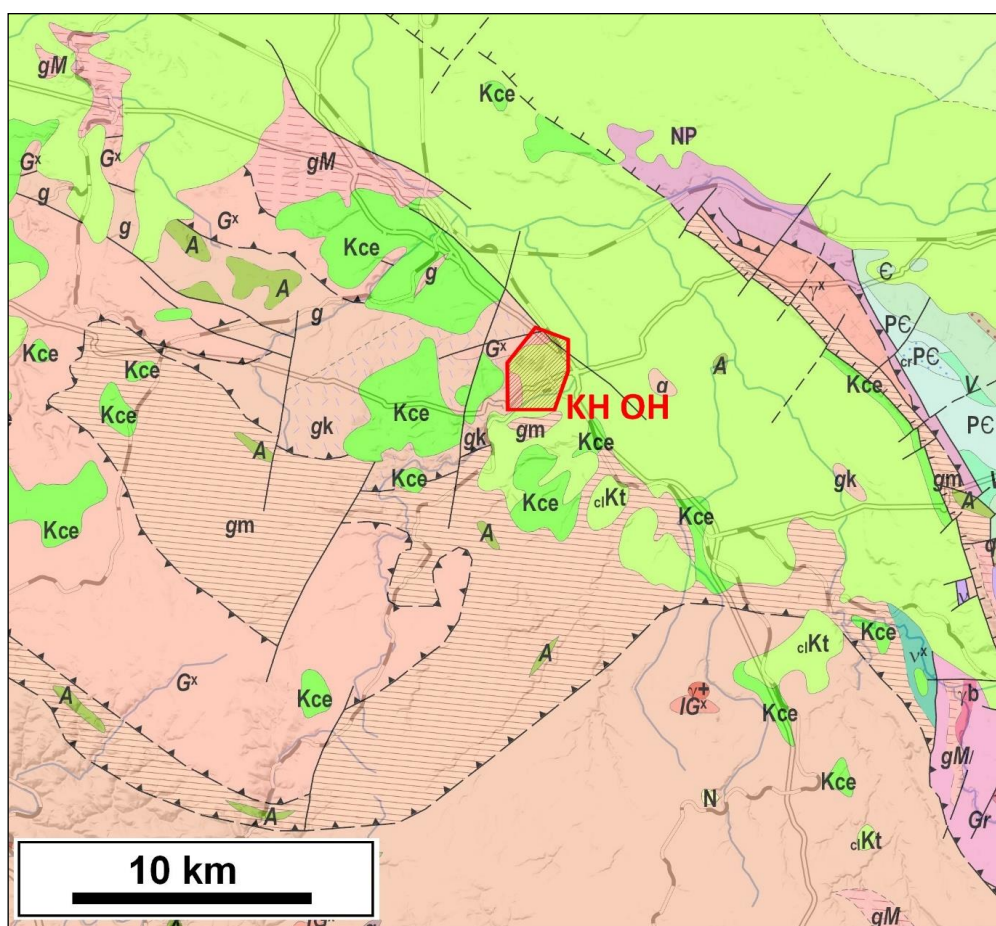


Figure 2: Geological sketch of the Kutná Hora-Svratka crystalline complex <https://mapy.geology.cz/geocr500/> (clKt – Cretaceous Turonian mudstones, Kce – Cretaceous Cenomanian sandstones and conglomerates, gm – mica gneisses, g- sillimanite- muscovite gneisses, gM – migmatitic gneisses, G^x – orthogneisses, IG – leucorate metagranites, A – amphibolites, NP- Neoproterozoic metaconglomerates, PE – Proterozoic slightly metamorphosed shales, V- slightly metamorphosed volcanic rocks, KH OH – Kutná Hora Ore District).



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Figure 3: The Kaňk Hill, view from the North. The rehabilitated tailing pond in front, abandoned mine on the left. (Photo D. Mašek, 2012)

2.2 Deposit geology

The genetic position, age (Lower Permian) and mineral composition links mineralisation in the Kutná Hora ore district to the postmagmatic katathermal mineralization connected with intrusion of the Variscan Central Moldanubian Pluton.

The ore district is formed by a system of parallel ore zones (“couk”) associated with faults in gneisses and migmatites of Kutná Hora unit. The most ore zones strike N-S and dip steeply (60-80°) to the W. The structures dipping to the W are mostly hydrothermally altered and their length attains from several hundred meters up to 3 km, occasionally up to 6 km. Vertical extent of the mineralized structures is up to 500-600 m. The common thickness of the vein zones is about several metres and the lateral extension of the alteration zones is as much as 27 m (Koutek 1964). The vein zones are located within an area of 10x4 km.

Mineralised veins contain polymetallic sulphide mineralization of Zn-Pb-Ag association. A higher content of Zn and Pb is typical for the northern part of district, where also enrichments of Cu and



Sn are present. On the other hand, larger amounts of the Sb were exploited from the southern part of the mining district.

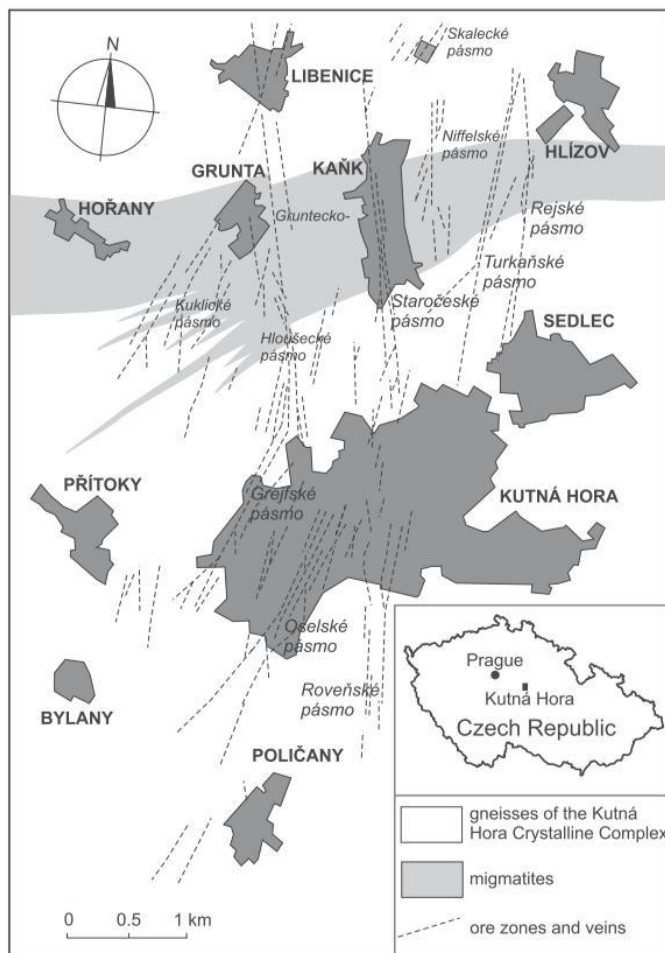


Figure 4: Figure 5-4 Kutná Hora ore district, ore zones and schematic geology (from Pažout, Sejkora and Šrejň, 2017).

2.3 Ore type (waste /ore), mineralogy

The type of mined ore was changing during time. In the beginning of mining, the miners were focusing on the ore containing native silver, silver bearing galena or other silver minerals. Later, also Cu minerals were exploited for small copper smelting. The Zn from sphalerite, Pb and Ag from galena were extracted during the 20th century. In was extracted from sphalerites, other indium bearing minerals are not known. The genetic development of the deposit can be divided into four development stages:



Development stage I:

- arsenopyrite period
- sphalerite-pyrrhotite period
- first period of carbonates (dolomite)

Development stage II:

- galenite – tetrahedrite – chalcopyrite period
- second period of carbonates (siderite)

Development stage III:

- period of noble Ag ores
- berthierite – antimonite

Development stage IV:

- quartz – pyrite – calcite

Arsenic is a dominant element, mainly in early development stages. The mineralogical development was described by Holub et. al. (1982). The ascending fluids were apparently acid and caused strong silicification. On the other hand, studies of primary halos have shown that Si and possibly also Fe, Sn, and S came from the country rocks. Arsenopyrite is concentrated in the deepest parts of the veins (based on known geochemical cross section) and its amount decreases upward. Arsenopyrite crystallized also in the surroundings of altered rocks. During the same development phase occurred also hydrothermal alteration, mainly silicification and sericitization in the immediate vicinity of the supply channel and chloritization further from the supply channel. In the same development phase were formed also primary halos characterized by the removal of chemical elements. There is a striking correlation between the amount of quartz and Fe in the veins and the composition of the rocks pierced by these veins. During the crystallization of quartz I., the tectonic movements were renewed, and the minerals of the second mineralization period began to be precipitate from the hydrothermal solutions. The minerals of this phase did not precipitate over the whole surface of the veins, the crystallization was rather in the form of sphalerite, pyrite and pyrrhotite ore shoots associated with stannite and chalcopyrite in the deeper parts and Ag enrichment in the upper parts.



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Figure 5: Abandoned mining shaft of Turkaňk mine with a mine tower. (Photo P. Rambousek 2013)

Towards the end of the first development stage, the first carbonates (dolomite, kutnahorite, etc.) crystallized in the upper part of the mineralised structures but they are missing in the deepest parts (evidence from the Hlavní vein). The second development phase with bulk sulphide crystallisation can be considered as a main ore forming period in the district. Quartz II. began to crystallize after the revival of the tectonic movements. This revival was intensive only in the upper part of the major structures, where galena mineralisation is separated from the older minerals by tectonic surfaces. Similarly, as chalcopyrite II. that replaces older minerals in the feathered veinlets. Chalcopyrite II. crystallized somewhat later than galena and occurred preferably in the deeper parts of the veins. Tetrahedrite had formed two distinct maxima. The first, more prominent one, is associated with galena in the upper parts of the veins. The second, less prominent, is associated with chalcopyrite II. The minerals of this development period occupy a considerably smaller part of vein surfaces than those of the first period. They tend to concentrate near a more structurally complicated parts of the mineralised zones. Another carbonates, mainly siderites and calcites were formed at the end of the second development stage. Both



development stages have the same scheme of zoning. The primary halos with the same scheme of zoning as in the major mineralised structures were formed simultaneously with the two stages.

After the change of the tensile stress field the horizontal movements on the fissures gradually predominated, whereby the western blocks moved to the south. The minerals of the third development stage occur as separate younger veinlets, mostly near the margins of older veins, and are separated by conspicuous structural surfaces or formed separate diagonal veinlets. The minerals of the third development stage show the same zoning as the previous stages but they occur even in the deeper zones of the mineralised structures. This stage is characterized by Sb enrichment and decreasing concentrations of Ag.

3 Mining history

The beginning of silver mining in the Kutná Hora ore district is probably connected with the mint of Slavník dynasty that was run in the end of the 10th century in the nearby village Malín. The real expansion of exploitation started in the second half of the 13th century, probably due to contributions of Cistercians from the monastery in Sedlec (part of the Kutná Hora). In the beginning of the 14th century, Kutná Hora (called Mons or Chuttis) represented one of the largest mining towns of Europe with advanced organization and technology. Mining boom in the Kutná Hora ore district was reflected in a significant improvement of an economic and power position of the Czech Kingdom and also led to a declaration of an important legal document, the Mining Law – *Ius regale montanorum* (around 1300), and establishment of the royal mint, where the famous Prague groschens were minted.

The exploitation started at first on natural exposures of “silver” zones, especially on the Kuklík Hill (where was probably mined firstly silver concentrated in eluvium), on the NW slopes of Kaňk Hill, on Rejsy lode and in Vrchlice river valley on Osel and Rovina zones. Ore mined from these locations was relatively easily to process. Intensive mining by the end of the 13th century successively revealed the rest of major ore zones of the district. In the first period, exploitation was carried out by shallow inclined shafts that were only 20 to 30 m deep.

Shafts for water drawing (“žentour” shafts) were built in the 14th and 15th century as a consequence of flooding in more deeper mining works. “Žentour” shafts were usually also inclined, distance between individual shafts was from 50 to 80 m, depth reached from 75 to 100, sporadically even 180 m, and was connected by many gates. Some mines in Kutná Hora (especially on Osel and Grejf lodes) represented difficult systems of inclined pits, gates, blind shafts, and other works in the 14th century. In the pre-Hussite period, some pits reached the depth even up to 450 m, which was at this time probably the World deepest mining works. There were tens of mines operated on every lode and even we often know their names, the precise localization is very difficult to point out nowadays. In the first half of the 14th century, the annual production of



silver was 6-7 t (90% of silver production in the Czech Kingdom) and about 1000-2000 people worked here. Number of workers increased to about 3000 people toward the end of 14th century. Apart from 6-7 t of silver also 50-100 t of copper were obtained that time. Crushed ore was processed in smelters, that were situated in nowadays Karlov, near the village Grunta, and also in the river valleys of Vrchlice and Bylanka. The operation of smelters required the use of pyritic sulphides (from the northern zones) and lead that served for segregation of silver from roasted ores or from raw “black” copper containing 1-2 % of Ag.

Copper represented a by-product of the smelters, but its production never overreached the local importance, because takings from it ranged only from 1 to 12 % of gross profit. Lead was imported from Poland, Harz and Korutany area from the second half of the 15th century. Stagnation of mining in the 15th century was probably caused by increasing expenses due to mining from greater depths, exhausting of rich silver lodes and also devastation and flooding of mines during the Hussites wars. A new mining boom started just before the end of the 15th century.

The second Ag production peak came in the second half of the 16th century. Huge workings were preserved in the depth of the Staročech lode from this mining period. There are parts of an old timber support here, galleries with “sublevels” that served for air supply and fume exhaustion during “fire-setting” mining method (the heat of a fire caused fracturing and easier workability of rocks). Ore on these northern lodes was poorer (200-300 g/t Ag) but veins were more massive. An average annual production of silver ranged from 2 to 4 t. The mines at Osel and also lower parts of Grejf, Kuklík, Hlouška and Rejsy ore zone were abandoned due to resources exhaustion from the half to the end of the 16th century.

To reduce the expenses of mine water drawing an advanced water-hoisting engine was built on Turkaňk zone above the Hlízov village in the second half of the 16th century. This machine was driven by a water wheel supplied by a canal from the Vrchlice River. Nevertheless, operating costs increasing continually following by profitability reduction and at the same time also a hard competition with cheaper silver from America, Krušné Hory (Erzgebirge) and other German deposits caused decline of all mines in Kutná Hora district at the turn of the 16th and 17th century. Mining had only a small extent and was restricted only on a trial mining after 1620.

Even the royal mint was liquidated in 1722 and Kutná Hora became the town of provincial character. Neither the reviving of mining on Turkaňk, Rejsy and Hlouška lodes at the end of the 17th and the beginning of the 18th century, nor the discovery of Skalecké ore zone in 1733 or experiments with exploitation from newly reopened Skalecká, Grejf, Rovina and Turkaňk shafts in the 1880's and 1890's did not have great extent or been successful.



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Figure 6: Picture from unknown gradual from the 15th century drawing the life of a mining town (CANTICA 2005). <http://cantica.kh.cz/grad/?page=stc>

The last development of exploitation in the mining district started after establishment of the German administration in 1939 just at the beginning of the World War II. Exploitation of polymetallic ores, especially Zn and Pb, started in the northern part of the ore district at the Turkaňk mine. This reviving, new exploration and building of flotation plant was followed by a mining of Rejsy and Turkaňk lodes (Rudné doly, Příbram). Utilized ores were sphalerites with Ag content (ore contained 1.5-2 % Zn and 20 g/t Ag). Simultaneously, intensive mineral exploration, field investigation and test borings of the whole mining area were carried out, especially in the northern part. Turkaňk mine, state enterprise, was finally closed in 1992, because production was no longer economic. Total mining production during 20th century was over 2,231 kt ore with Zn content about 2% Zn (Hušpauer and Mikuš 1995).



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Figure 7: Area with tailing pond after rehabilitation. (Photo D. Mašek 2013)

3.1.1 Raw material potential

The State mineral balance register today ca. 2570 kt of ore (Cu, Zn and Pb ore and polymetallic ores), with 41 t of Ag (ore grade 33g/t) and 76 t of In (ore 30 g/t). Additional prognostic resources are expected in old tailings (base metals, Ag, potentially In).

Beside the activities covered in the FRAME project, CGS is also starting a new project (supported by the Ministry of the Environment), that includes the prognostic evaluation of primary sources from the part of Kutná Hora unit hidden under sedimentary cover and also new technology for In extraction from ore concentrates without smelting. Both projects will profit from each other.

All mines in Kutná Hora ore district are closed and mine works from 20th century are flooded by acid mine waters. Economics of the remaining reserves of polymetallic ore with Ag, In and Bi content will be depended on the world market prices of these commodities.

4 New investigations

New investigations for In in the Kutná Hora ore district started in 2013. Czech Geological Survey started a small project based on sampling of tailing pond and the rest old dumps from 20th century. 9 boreholes with maximal depth to 4 m were made using a hand drilling equipment. 26 samples were taken from boreholes and 6 additional samples from the old dumps. In 2014, the project was unfortunately stopped before all samples have been fully analysed. Preliminary data from this project are shown in table 1. In is expected in the samples with the highest content of



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base metals, but it was in very small portions. New analyses were made from archive tailing concentrates within the FRAME project in 2020 – 2021. 11 new analyses were focused to analyse contents of base metals together with In and Cd. Mineralogical investigations of 2 samples from Staročeské ore zone was carried out on electron microscope with EDS and WDS detectors.

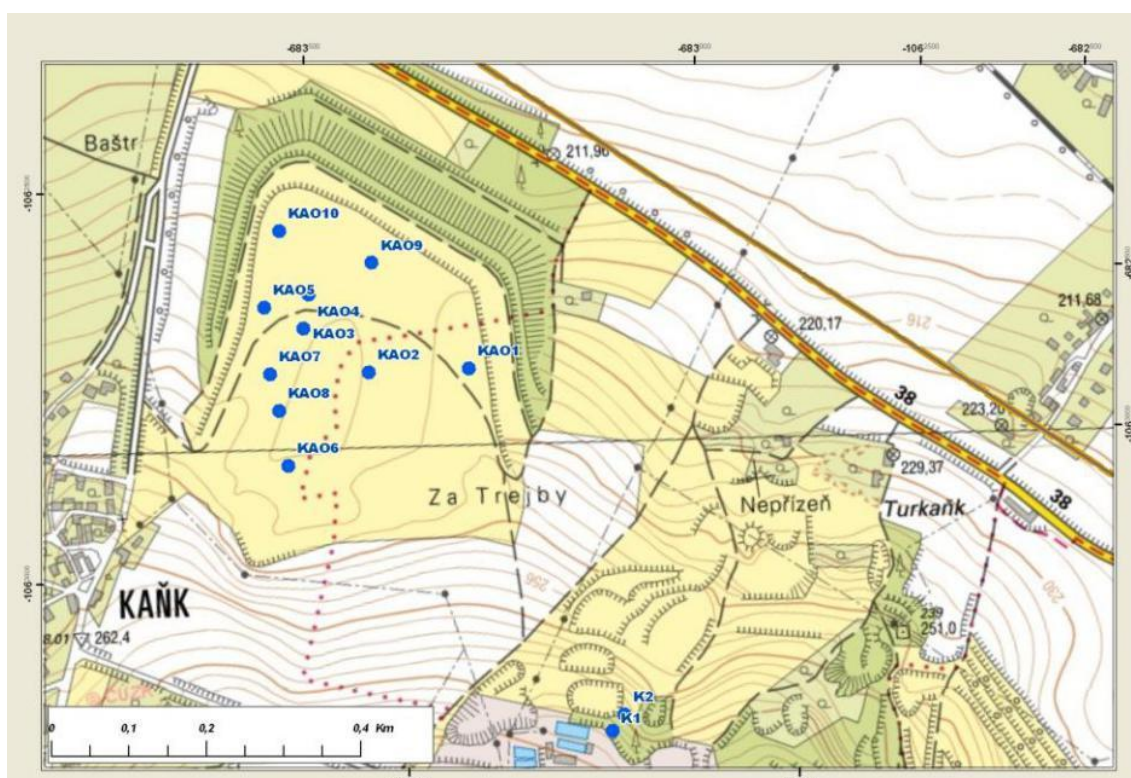


Figure 8: Sampling locations from the area of Turkaňk mine and Turkaňk tailing pond. (Petr Rambousek, 2014).



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Table 1: Preliminary analyses of samples from tailings by PXRF method (2014)

Borehole (2014)	Sample	m	Cu ppm	Zn ppm	As ppm	Sr ppm	Zr ppm	Ag ppm	Cd ppm	Sn ppm	Sb ppm	Ba ppm	Pb ppm
KA01	1	0,00-0,15	46	538	984	41	113	72	5	1 319	308	643	2 730
KA01	2	0,15-0,6	32	639	736	78	116	49	5	1 067	256	1 075	1 879
KA01	3	0,6-1,0	301	4 425	2 911	276	104	5	72	532	5	6 806	1 529
KA01	4	1,0-1,3	991	10 901	9 800	452	114	5	85	385	5	14 502	2 460
KA01	5	1,3-2,65	1 062	9 945	5 877	462	85	5	160	423	119	14 819	1 795
KA01	6	1,3-2,65	500	11 840	7 388	123	88	5	266	489	5	4 687	1 030
KA01	7	2,65-2,75	193	9 082	2 457	49	61	5	49	544	5	485	249
KA01	8	2,75-3,0	892	12 014	2 925	167	46	5	129	451	118	1 699	425
KA01	9	3,0-3,4	128	5 478	3 371	48	103	5	5	432	5	740	281
KA01	10	3,4-3,8	131	5 562	2 255	53	88	5	58	402	5	428	248
KA02	11	0,0-0,4	725	12 938	2 325	450	98	5	65	440	5	23 437	935
KA02	12	0,4-0,7	1 332	8 388	487	684	287	5	53	362	130	26 141	1 072
KA02	13	0,7-1,1	450	7 217	2 493	601	133	5	74	343	130	23 478	1 234
KA02	14	1,1-2,0	520	9 171	5 172	154	97	5	128	665	116	5 743	493
KA02	15	2,0-2,5	659	5 904	2 359	113	87	5	67	433	84	2 353	180
KA02	16	2,5-3,0	268	2 958	2 553	90	109	5	5	421	5	1 797	171
KA02	17	3,0-3,5	230	2 210	3 639	43	132	5	5	380	5	648	75
KA02	18	3,5-4,0	348	2 275	3 001	88	125	5	5	384	5	787	89
KA04	19	1,6-2,0	445	7 794	6 735	188	110	5	82	560	5	5 814	514
KA04	20	2,0-2,6	304	4 240	4 520	88	91	5	5	491	5	1 807	167
KA04	21	2,6-3,0	415	3 612	1 782	365	74	5	5	320	89	8 344	237
KA04	22	3,0-3,8	322	2 333	1 285	172	73	5	5	248	5	1 501	101
KA04	23	3,8-4,0	470	3 531	1 749	152	89	5	5	367	5	2 131	128
KA07	24	0,7-1,0	532	11 403	2 317	466	96	5	115	326	5	19 839	916
KA07	25	1,0-1,7	512	8 663	2 323	240	73	5	103	419	5	7 009	466
KA07	26	1,7-2,1	280	4 320	821	170	35	56	5	173	5	1 891	173



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Figure 9: Hand-drill sampling and documentation from old tailing pond Turkaňk (Photo D.Mašek 2012).

Table 2: Content of ore elements in archive ore concentrates from Turkaňk mine (Laboratory CGS, ICP-MS, 2021).

	Ti	Ni	Cu	Zn	Ge	Ag	Cd	In	Pb	Ba
No s.	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
KC556	117	37,2	64,0	266,5	20,8	54,6	4,0	1,0	698,5	502,8
KC562	164	31,1	169,1	1849,5	20,7	106,6	7,3	4,6	2938,0	447,6
KC563	43	40,4	2198,0	10560,	6,7	312,0	38,3	11,8	527300,	227,1
KC564	94	21,9	5447,0	360350,	12,9	172,7	1443,0	346,5	2576,5	271,3
KC565	175	26,0	10390,	378400,	10,4	289,6	1650,0	439,0	2965,0	457,2
KC566	99	29,5	196600,	34210,	11,5	128,6	143,9	82,8	963,0	619,2
KC567	297	91,8	150000,	83700,	12,0	189,6	368,3	87,8	1073,5	779,6
K1	306	14,4	100,7	2141,0	19,6	267,6	23,7	11,9	2284,5	100,5
K2	278	14,5	116,0	194,8	19,4	98,6	4,0	1,4	667,0	603,2
SRA	3473	18,7	33,0	318,0	4,6	29,3	2,6	0,5	335,0	234,1
SRB	2306	19,4	27,1	399,0	4,1	22,2	1,7	0,5	204,5	339,6



The contents of In (up to 439 ppm) in concentrates are in good correlation to contents of Zn (up to 37,8 %) as well as to Cd (up to 0,16 %). These relations indicate that the main source of In is sphalerite. Lower amounts of In (up to 87 ppm) are in samples with higher content of Cu, also chalcopryrite is known as the host mineral of In. The content of Ag is not in strong correlation with In. In addition, the regular relationship between Fe and In is not clearly visible from previous microprobe studies as is shown from table 5-3.



Figure 10: The rest of tailing concentrate from Turkaňk mine, sampling point K1 and K2 (Photo P. Rambousek 2012).

Table 3: The results of microprobe investigation of sphalerites from Kutná Hora ore region (Šrein 2017)

Sampling place	Nr. of samples	Fe (%)	Cd (%)	In (%)
Shaft No. XIX (Sedm lánů)	6	0,09 - 9,11	0,16 - 1,72	0
Zone Staročeské pásmo	11	8,86 - 10,75	0,40 - 0,60	0,17 - 0,27
Mine Panská	3	11,58 - 11,94	0,28 - 0,36	0
Mine Turkaňk	4	10,55 - 11,17	0,46 - 0,50	0

New mineralogical investigations were made on 2 polished samples. They were investigated using equipment Tescan Mira3 with an EDS X-MaxN (Oxford Instruments) analyser for mineralogical composition and distribution of important elements in sphalerites grains. The results are shown in Fig. 11. The samples were taken from the archive collection and thus probably cannot represent all mined ores.



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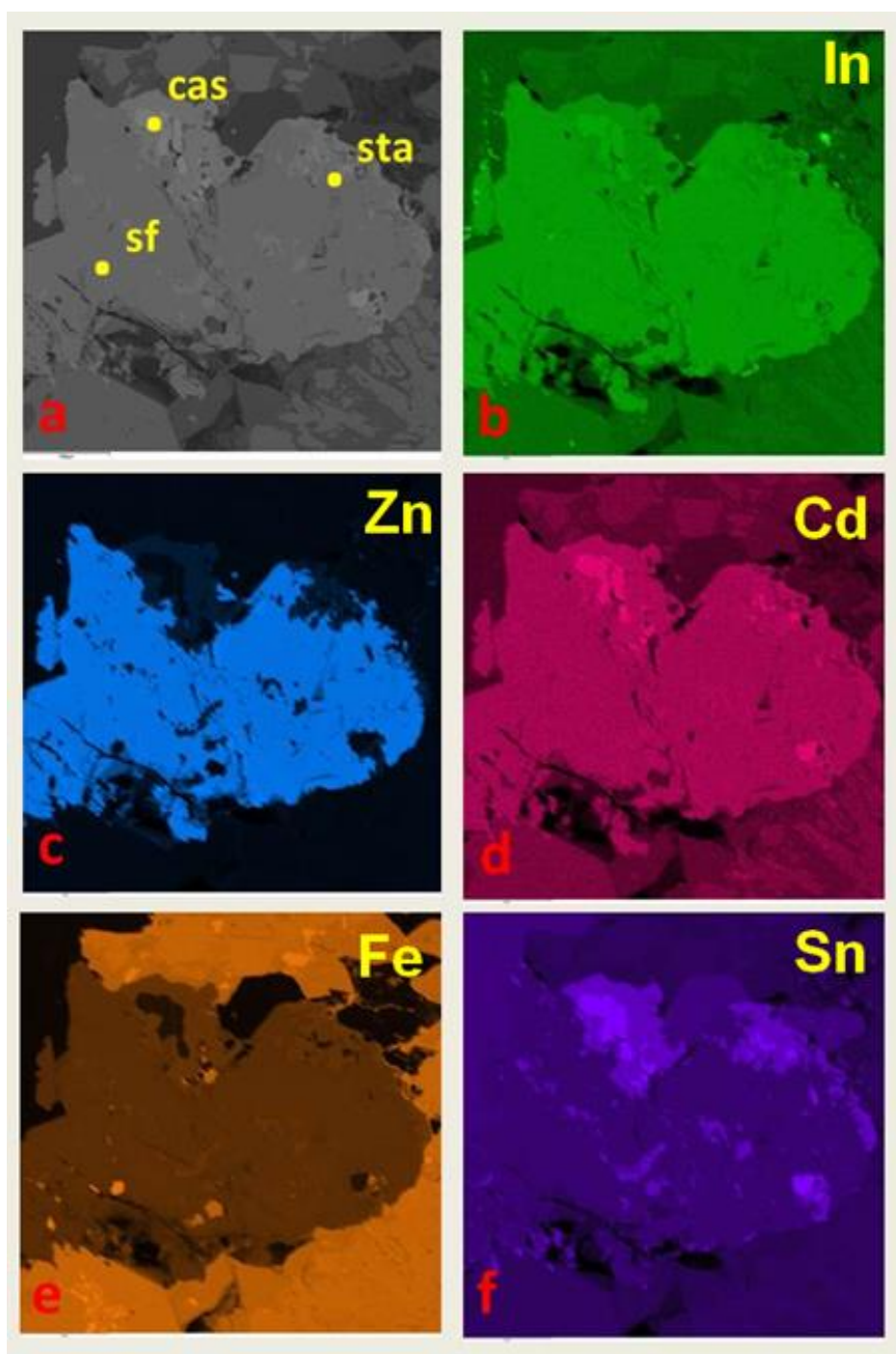


Figure 11: Example of sphalerite grain in ore vein from Staročeské ore zone. a) sphalerite aggregate (sf) with inclusions of cassiterite (cas) and stannite (sta). Outside of grain are quartz, galena, pyrite and arsenopyrite; b-f) element distribution map for In, Zn, Cd, Fe and Sn



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Results from the new investigations are in good relations with the older ones. Indium is connected with sphalerites, but only to a small concentration in the newly studied samples. Lower concentrations of In were observed also in cassiterite inclusions. The content of In is in good correlation with higher contents of Cd as it is visible from chemical analyses of ore concentrates and from EDS element map.

4.1 Present status

The FRAME projects partners from Poland, Germany and the Czech Republic visited the area of the closed Turkaňk mine and surroundings with remnants of medieval mining at the Kaňk hill and Kaňk village during the WP7 field trip in October 2019.



Figure 12: Little memorial in memory of the end of mining activity on Turkaňk mine. Excursion of the FRAME project 10/2019. (Photo P. Rambousek 2019)

Mine Turkaňk from 20th century is now flooded and acid water with high content of As, Fe, Zn, Mn is pumped into neutralise and decontamination station in the place of former flotation plant.



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The decontamination is based on lime technology. The input concentrations of harmful elements are 40-70 mg/l of As, 1600-2200 mg/l Fe, 36-43 mg/l Mn, 120-170 mg/l of Zn. Purified water flows through sedimentary ponds and then continues to the Šifovka creek and to the Labe (Elbe) river with following parameters: As under 0,01 mg/l, Zn 0,048-0,080 mg/l, Fe 0,050-0,32, Mn 0,02-0,26 (taken after DIAMO report 2017). All output values are below the Czech standard for surface water.

Different situation is present directly in the Kaňk village with the remnants of a medieval mining activities like old dumps and collapsed surfaces in the place of old mining works. The influence of As from primary and secondary minerals is monitored over 50 years. The studies on the quality of drinking waters, influence on the health and soil contamination were made for the Kaňk village and the town of Kutná Hora. Some more critical dumps were partly rehabilitated, the monitoring system and new water pipelines from safety water sources were made. But water use for gardening or refrigeration from local source is very limited. For example, the waste dumps from the Staročeské ore zone are heterogeneous, with particles ranging from very fine (clay) to coarse (tens of cm), including barren gneiss host rock, hydrothermally altered and mineralized rocks. The waste dumps are characterized by high to extreme levels of As (up to 2.68 wt.%) and high contents of Cu (up to 0.1 wt.%), Pb (up to 0.03 wt.%), or Zn (up to 0.1 wt.%) (Kocourková-Víšková et al., 2015).

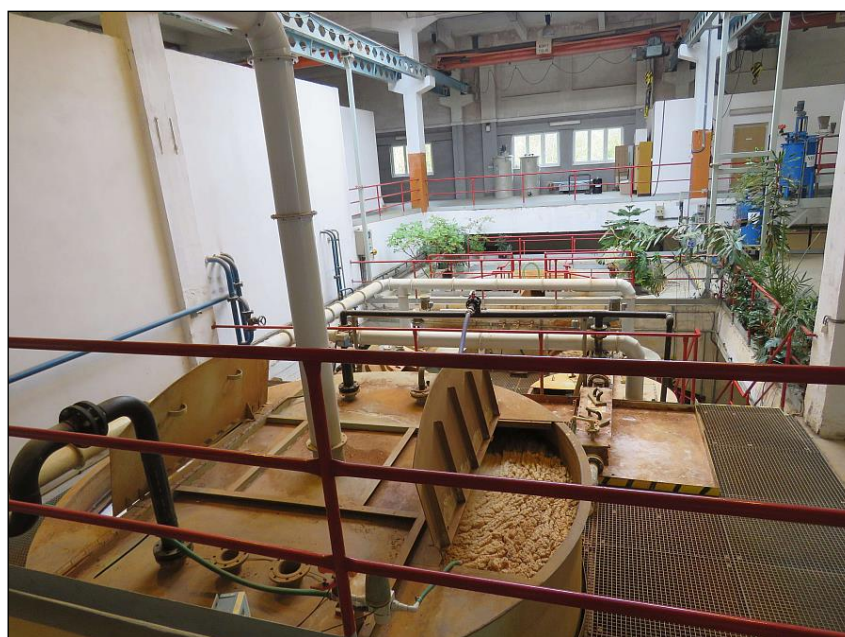


Figure 13: The neutralization and decontamination station on Turkaňk mine in the place former flotation plant. (Photo P. Rambousek 2019)



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Figure 14: The residue of medieval mining dump in the centre of Kaňk village containing high volume of As minerals. (Photo P. Rambousek 2019)

Risky As present in the mining waste precipitates as sulpharsenate minerals but was found also as adsorbed and/or coprecipitated with minerals of jarosite subgroup ($\sim \text{AFe}_3(\text{SO}_4)_2(\text{OH})_6$, where A can be: Na^+ , K^+ , H_3O^+ , or 0.5Pb^{2+}), schwertmannite ($\sim \text{Fe}_8\text{O}_8(\text{OH})_6\text{SO}_4$) and Fe^{+3} oxyhydroxides. Rainwater percolating through the mining wastes leaches pollutants from these secondary phases and probably seeps into and contaminates shallow groundwater. Chemical composition of the groundwater in the shallow aquifers is highly variable but can be locally very acidic (pH 1.39) and containing up to 1440 mg /l As, 10 g /l Fe, and 28.6 g /l SO_4^{2-} .

The second problem is a surface stability in a populated area, which disturbs daily life in the old mining town. The old mining works are investigated for many years using different methods. Employees of the Historical mining archive in Kutná Hora, department of Czech Geological Survey are studying archived old mining maps from Kutná Hora dating as far as the beginning of the 16th century. They are also constructing borders of undermined areas from these sources, incorporating it into Czech national information system of old mining sites and undermined areas. This information system gives basic information about extent of a risk area, type of mining works and historically mined commodity. The second important activity, especially in Kutná Hora, is underground exploration of mining works that results in discovery of new underground spaces



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and new maps of mining works. Next necessary activities, mainly at new building sites, are geophysical measuring and direct drilling exploration.



Figure 15: The study of historical mining maps in archive of the Historical mining department ČGS in Kutná Hora. (Photo P. Rambousek 2019)

5 Conclusions

The Kutná Hora ore district is very old mining site with famous history. The ore district comprises a system of subparallel ore veins and ore zones associated with faults in regionally metamorphosed rocks of the Kutná Hora metamorphosed complex built by biotite-muscovite gneisses and migmatites intercalated with amphibolites, eclogites, and serpentinites. Several hundred mines produced silver-bearing polymetallic ores from the end of the 13th century to the age of Industrial Revolution. About 2000–3000 metric tons of silver were extracted from local ores. The last mining activity in the mining district was exploitation of polymetallic ores, especially Zn and Pb at the Turkaňk mine started in 1939. The new flotation plant with tailing pond was built in the 50s of the 20th Century. Utilized ores were mainly sphalerites with Ag content (the ore contained 1,5-2 % Zn and 20 g/t Ag). Simultaneously, intensive mineral exploration, field investigation and test borings of the whole mining area were carried out with focus in the northern part. Turkaňk mine, state enterprise, was finally closed in 1992, because production was no longer economic. Total mining production during 20th century was over 2 231 kt ore with Zn content about 2% Zn (Hušpauer and Mikuš 1995) but In was not produced. DIAMO s.p., present



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state owner of the mine, is carrying out rehabilitation of the mining area and ensures purification of mining water, mainly As that represent the most risk element in whole mining region. The State mineral balance register today ca. 2570 kt of ore (Cu, Zn and Pb ore and polymetallic ores), with 41 t of Ag (ore grade 33g/t) and 76 t of In (ore 30 g/t). Additional prognostic resources are expected in old tailings (base metals, Ag, potentially In).

New interest in CRM underpinned intentions to investigate possibility of In extraction from old dumps and tailings. CGS started new investigations in 2011, but it was stopped after one year of project duration. New investigation covered by the FRAME project represented a chance for new analyses and basic investigation of this area. Indium, as the main CRM in the area, has very irregular distribution, is intimately connected with sphalerite and has strong correlation with cadmium. Content of In in samples from the tailings is very low (based on previous studies), archive analyses yielded values from 0,17 – 0,25 % in Zn ore concentrate. New analyses from a primary source suffer by a very heterogenic concentration of In in sampled specimens, thus these samples are not necessarily represent typical contents form In bearing zone. Ores from old dumps and mineralogical collections are mainly without precise localization, thus the mineralogical and/or chemical results are not too representative. Also, drill cores from intensive exploration campaign were not archived.

Based on mining reports and calculated reserves/resources, the most promising part for possible future exploration would be the northern part of the ore district with Skalecké and Nefelské ore zone under the Cretaceous sedimentary cover, possible up to the Labe (Elbe) river in the North.

6 Data sources used

The study is use information from archive of state company DIAMO, reports from the time of Turkaňk mine and processing plant construction (from 50th years of 20th century. Other materials were taken from Czech Geological Survey archive (<http://www.geology.cz/app/asgi/>) and other applications like old mining works, undermined areas, inventory of mining waste facilities:

https://mapy.geology.cz/oznamena_dulni_dila/
https://mapy.geology.cz/dulni_dila_poddolovani/,
https://mapy.geology.cz/inventarizace_uloznych_mist/
<http://www.geology.cz/app/asgi/>

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