

Geological survey, resources and properties of the Ag and Au containing ore in the Kremnica-Šturec deposit, Slovakia

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Geological situation on the Kremnica-Šturec deposit are currently well examined. Prognostic mineral resources calculated by the Snowden Mining Industry Consultants, in compliance with the requirements of the JORC Code are as follows: 15.4 Mt of ore with the average metal content of 1.75 g t⁻¹ of gold and 14.9 g t⁻¹ of silver in the categories of measured and indicated resources. Additional 9.7 Mt of ore with the average metal content of 0.89 g t⁻¹ of gold and 5.1 g t⁻¹ of silver in the category of inferred resources (all the data are for the marginal sample of 0.40 g t⁻¹ of gold). Preliminary study is elaborated on the basis of these prognostic mineral resources (Ortac Resources Ltd).

At present, the deposit development, preparation and mining is being considered and the excavation of the reserved deposit using the underground mining method is being prepared for the purpose of excavation of ores containing Au and Ag.

Key words: gold, silver, ore veins, resources, Slovakia

Introduction

The Kremnica-Šturec deposit is located in the central volcanic area in the Kremnica Mountains of the Western Carpathians. Deposit is the most important and the largest deposit of low-grade precious-metal ores in Slovakia. With its extent, amount of reported resources and prognostic resources, it is suitable for underground and open-pit mining.

The deposit is located near the mining and mint town of Kremnica in the Central Slovakia (Fig. 1) and covers approximately 1.2 km long section out of 6.5 km long vein system. Mineralization on the Kremnica-Šturec deposit reaches the width of 120 m and extends approximately to the depth of 300 m under the surface.

In the deposit, there are approximately 120 known veins structures gathered into four main vein systems. Out of them, only veins systems 1 and 2 were economically attractive in the past (Böhmer, 1966). The veins are of the N-S to NNE-SSW direction and occur mostly in andesites and diorites of the Zlata Studna formation, which are hydrothermally altered to various extents (Bakos and Chovan, eds. 2004; Števkó et al., 2009).

The Kremnica-Šturec deposit belongs to the vein system 1. The main ore veins are bound to the fault system developed on the eastern contact of the intrusive body, or several bodies of andesite magma. The overall geological situation, morphology of main ore veins, and arrangement of pinnate veins correspond to the descending dislocation. Tectonic movements created the conditions for the formation of pinnate veins and the movement of hanging wall and foot wall rocks into free space along the fissures. Huge veins and vein bands were formed, with significant indicative and depth extent. Entire vein band consists of two main structures, the Schrämen and the Hlavna (Fig. 2), which intersect (Bergfest, 1956; Böhmer, 1966, 1985).

Chemical composition of the ore

Chemical composition is identified on the basis of the exploration wells (Tab. 1) and the passage to the treatment station at the time of the pilot operation aimed at processing the ore from deposit by direct cyanation. It characterizes the vein structure together with intra-vein andesites. The results obtained from the processing of approximately 50 kt of ore from the open-pit mine in years 1986 – 1992 are optimal for the assessment of the ore chemical composition.

Tab. 1. Chemical composition of the gangue.

Chemical composition [%] from the exploration wells							
SiO ₂	Al ₂ O ₃	Fe ₂ O ₃ + Fe	CaO	SO ₃	MgO	K ₂ O	Other
47 – 65	13 – 18	3 – 12	3	6	2	5	less than 1

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Chemical composition of the treated ore – analysis of the daily passage into the ball mill – accompanying metals: Fe 3 %, S 2.5 %, Sb 0.11 %, As traces, Ca 0.3 %, Cu 0.05 %, and a useful components: Au 2.1 g.t⁻¹ and Ag 6.4 g.t⁻¹.

Physical, mechanical and technological properties of ore veins

The deposit consists of the mineralised veins zone with a sharp border based on the geological knowledge and metal content of the material. It mostly consists of hydrothermal flint. The intra-vein zone is filled with kaolinized andesites containing flint veins of various thicknesses.

From the mineralogical point of view, the ore veins are monotonous. The vein mass was formed on the basis of intermineralization tectonics into six sedimentary periods. As for ore minerals, the most frequent one is pyrite, lower-quality marcasite and arsenian pyrite. In the accessory amounts there are carriers of gold and silver mineralization. Useful components in the excavated ore precious metals (Au, Ag) are of sub-microscopic sizes. They occur either separately in the gangue, partially in the surrounding rock. Gold (electrum) occurs in two environments:

in the Au-bearing pyrite in form of inclusions of sizes ranging between 5 and 45 μm

in the flint in form of Au flakes with sizes ranging between 1 and 5 μm

Gold occurs in Au flakes in form of electrum (Au content 65 %, Ag content 35 %). A dominant form of Au occurrence in surface and near-surface reserves of ores on the deposit is Au flakes of sub-microscopic sizes in flint (approximately 80 to 100 %). About 15 % of Au flakes occur in form of adhesions of aggregates of Ag minerals, pyrite and marcasite. Approximately 5 % occur in form of inclusions in pyrite. Its percentage in the total content of ore minerals in the gangue ranges between 7 and 9 vol. %, the average is 8.0 vol. %.

Silver is represented by a varied range of silver minerals; their probable percentage in the gangue is as follows: polybasite > silver tetrahedrite > pyrargyrite > proustite > argentite-pearceite > miargyrite-stephanite. A dominant amount of silver minerals in the fillings of vein structures occurs in form of aggregates of xenomorphic monomineral grains, less polymetallic (pyrite + gold \pm polymetallic sulphides), or separate grains in flint. Grain sizes vary from large macroscopic to sub-microscopic sizes (interval 0X – X00 μm). Its percentage in the total content of ore minerals in the gangue ranges between 8 and 11 vol %, the average is 9.5 vol. % (Štubňa, 1985; Maťo, 1989; Bakos et al., 2004). Silver is bound to silver sulphides and sulphosalts.

Physical and mechanical properties follow from the veins structure type. Flint in the crystal form, but mostly chalcedonic-glassy, is hard to process. Requirements are high, as for the quality of used material for drilling and processing in the treatment plant. Occurrence of gold flakes of microscopic dimensions requires grinding of the material into the size at least 80% under the 200 mesh. It complicates the grinding process (necessary in several degrees), increases the time demand, and restrains the outputs in the separation. Bulk density of ore is about 2.4 t.m³.

Useful component content

It is variable in the geological resources in the spatial composition. Average amount is 2 g.t⁻¹ of Au. Underground mining in Kremnica-Šturec enables free access to the resources with the metal content that represents the average quality of ore resources suitable for excavation and processing. It is not possible to regulate the excavation based on ore quality depending on the assessed geological blocks. Therefore, it is impossible to select “rich” ore.

Harmful substances contents

None were observed in the deposit substance. Flint gangue is monotonous and the content of accessory minerals does not cause toxicity of the excavated material. This follows from the chemical composition of the ore excavated in the past.

Characteristics and properties of rashings (inserts in the deposit)

In the deposit substance they are formed by altered pre-silica andesites. The detailed geological survey observed that the alterations around the ores influenced the development of these structures. Aureoles around the flint veins are rich with the electrum mineral (zones thick about 2 m) and represent recoverable resources of “ore”. Rashings thick more than 5 m were excluded from the resources calculation. They will be excavated within the preparation works. With regard to the presence of rock-forming minerals they are not toxically hazardous on the disposal sites.

Characteristics and properties of rocks and soils in foot wall and hanging wall

Foot wall and hanging wall contain andesites with various degree of alteration, included into the Zlata Studna formation (Lexa). In the past, they were named “old”. Their physical, mechanical and technological properties are identical to those of andesites used for the construction and similar purposes. (For example

the quarry stone for the construction of roads, dustings, bases under the structures). They do not contain useful components that could be used for other purposes.

Geological survey of the deposit and the assessment thereof

From the historical point of view, it is necessary to mention the long-term efforts of geologists in verification of ore resources in veins of the vein system 1. Extensive and systematic exploration works were carried out by several organizations, especially after 1954. In 1961, the attention was paid to the central part of deposit. Quantity and quality of ores containing gold and silver were proved in the rift valley area. The results served as the base for the exploration carried out by the Rudné bane n. p. national undertaking in Ferdinand and Šturec tunnels (until 1965). In 1966, other exploration works were carried out by the GP n. p. national undertaking from Spišská Nová Ves (Nová Baňa and T. Teplice). The results of these efforts were presented in the resources calculations. In years 1972 – 1982 the exploration works were discontinued. They were restored after 1982. Rudné bane n. p. national undertaking prepared the project of the detailed geological survey for the central part of Šturec. Mining works were carried out in tunnels Andrej and Milan. They demonstrated 6,856.7 kt of ore in the inferred (Z-3) category with the average Au content of 1.52 g t⁻¹



Fig. 1. Kremnica Mountains in Slovakia.

(calculated for Ag) (Bergfest, 1956; Filo et al., 1980; Štubňa, 1985; Ďurčo, 1990; Finka, 1995).

Extensive geological survey of the veins in the vein system 1 in the northern, central, and southern part of the deposit area was carried out by the Canadian company Argosy in years 1996-1997 by performing the drilling works from the surface. In this period, in the area of the deposit territory, the Argosy Slovakia s.r.o. company drilled 79 inclined and vertical boreholes in the total length of 12,300 m. It provided the more detailed information on the ores containing gold and silver, recoverable by underground mining in the Šturec area.

Another deposit accumulation was proved by the Argosy company in the Kremnica Mine area (on veins Kirchberg-Wolf, Hlavná).

In the area north of Šturec, they registered the near-surface resources of gold and silver ores in Schrämen, Teich, and Schindler veins (exploration verifying and calculating the resources was carried out by the company GP SNV GO B. Bystrica in 1992) as a part of the assignment “Kremnické Bane – Šturec, north”.

Calculation of resources on the deposit accumulation Šturec and Wolf was carried out by the Western Services Engineering Inc. for the Argosy Mining Corporation. The calculation was elaborated in two alternatives (for marginal samples 0.5 and 1.0 g t⁻¹ of Au).

Alternative 1 – marginal sample 0.5 g t⁻¹ Au+Ag (calculation 50 g of Ag = 1 g of Au) (Tab. 2). Alternative 2 – marginal sample 1.0 g t⁻¹ Au+Ag (calculation of silver to gold) (Tab. 3)

Tab. 2. Alternative 1 - Resources of Z-2 (indicated) + Z-3 (inferred) categories.

Deposit object	Resources quantity [kt]	Au content [g t^{-1}]	Ag content [g t^{-1}]	Au+Ag content [g t^{-1}]	Au quantity [kg]	Ag quantity [kg]
Šturec	19,063.1	1.53	11.1	1.75	29,166.5	211,600.4
Wolf	2,161.6	1.28	20.5	1.69	2,766.8	44,312.8
Vratislav	1,060.0	2.18	21.6	2.61	2,310.8	22,896.0
Total resources	22,284.7	1.54	12.5	1.78	34,318.4	278,558.8

Tab. 3. Alternative 2 - Resources of Z-2 (indicated) + Z-3 (inferred) categories.

Deposit object	Resources quantity [kt]	Au content [g t^{-1}]	Ag content [g t^{-1}]	Au+Ag content [g t^{-1}]	Au quantity [kg]	Ag quantity [kg]
Šturec	13,303.2	1.90	13.8	2.17	25,276.08	183,584.2
Wolf	1,715.5	1.48	21.3	1.91	2,538.9	36,540.2
Vratislav	595.0	3.33	24.7	3.58	1,981.4	14,696.5
Total resources	15,613.7	1.91	15.0	2.20	29,822.2	234,205.5

By the intensive drilling exploration in the Šturec area, the Argosy company demonstrated the significant amount of geological resources of ores containing gold and silver recoverable by surface mining, (more than 19 mil. tons) with the metal content of 1.53 g t^{-1} of gold and 11.1 g t^{-1} of silver.

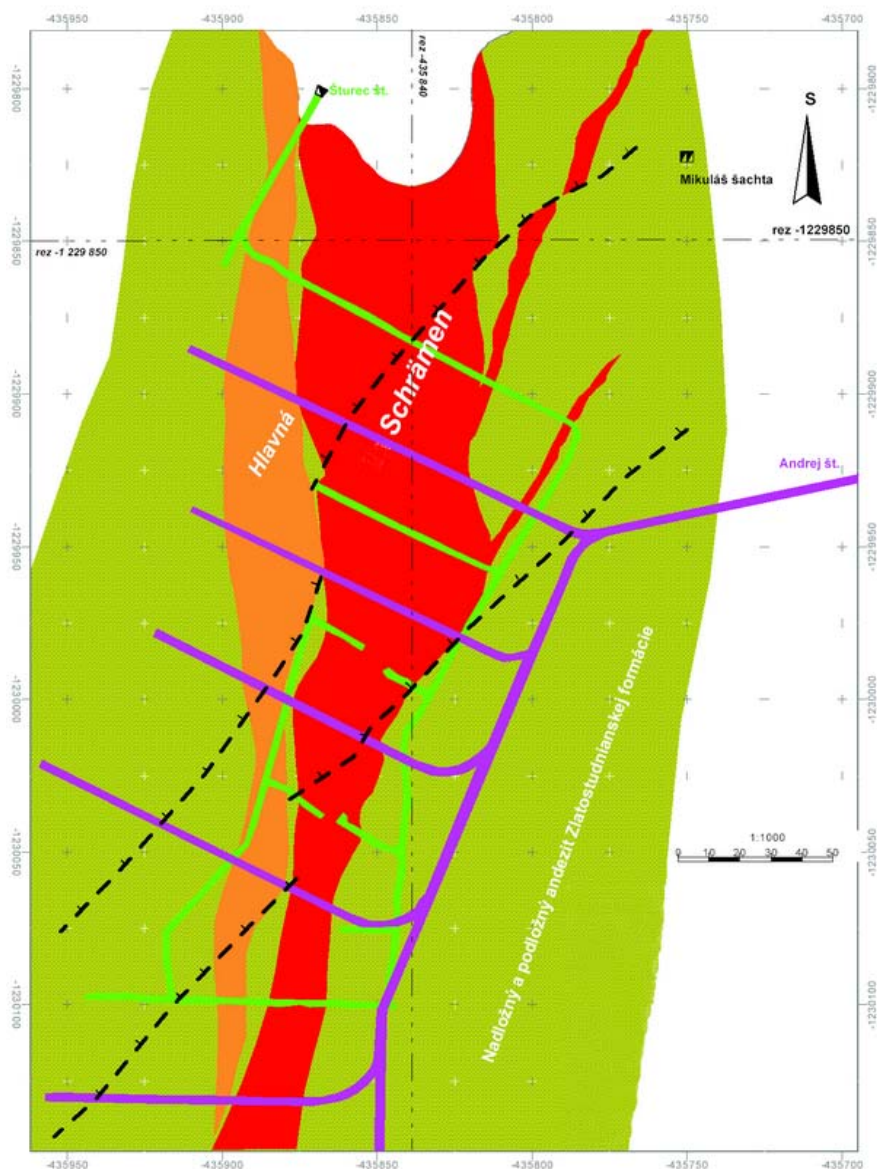


Fig. 2. Horizontal geological cross-section of the Kremnica-Šturec deposit (657 metres above sea). Hlavná and Schrämen veins.

Further exploration in Kremnica-Šturec was carried out by the Tournigan company from Canada in years 2004-2005. In their calculation dated 31 July 2006 they revaluated and specified in more details the geological resources and calculated in the Z-1+Z-2 category (balance) 18,907 kt of ore (gold 1.59 g t⁻¹, silver 12.78 g t⁻¹), in the Z-3 category it was 6,938 kt (Au 1.32 g t⁻¹, Ag 7.42 g t⁻¹) (Bartalský et al., 2006).

The calculation was made using the conditions for the content of 0.75 g t⁻¹ AuEq (calculation of silver content to gold content in the ration 66.7:1). The margin of 0.75 g t⁻¹ AuEq is a sufficient threshold for a real possibility of excavation using the underground mining and processing of ore containing gold and silver from Šturec. Based on the results of the drilling exploration, the resources were calculated as 958,000 oz t of gold (29,903.876 kg) and 7,729,300 oz t of silver (240,359.45 kg) in 18,807,000 t of geological resources in the category of measured (Z-1) and indicated (Z-2), with the average Au content of 1.58 g t⁻¹ and Ag content of 12.78 g t⁻¹. In the resources inferred (Z-3) 271,500 oz t of gold (8,445.107 kg) and 1,526,300 oz t of silver (47,466.33 kg) in 6,398,000 t of ore with the average gold content of 1.32 g t⁻¹ and silver content of 7.42 g t⁻¹ (Tab. 4).

Tab. 4. Total resources on the deposit as of 31 July 2006.

Resources category	Resources amount [t]	Content Au + Ag			Au + Ag metal content		
		Au [g.t ⁻¹]	Ag [g.t ⁻¹]	Calc. to Au	Au [kg]	Ag [kg]	Calc. to Au
Z-1	7,293,229	1.75	14.24	1.96	12,763.151	103,855.58	14,294.729
Z-2	11,514,240	1.48	11.86	1.66	17,041.075	136,558.89	19,113.638
Z-3	6,397,808	1.32	7.42	1.44	8,445.107	47,466.33	9,212.845
Z-1+Z-2	18,807,469	1.59	12.78	1.78	29,903.876	240,359.45	33,477.295
Z-1+Z-2+Z-3	25,205,277	1.52	11.42	1.69	38,312.020	287,825.78	42,627.250

On the Kremnica-Šturec deposit, more than 25.2 mil. tons of geological resources of Ag and Au containing ores, recoverable using the surface mining, are proved in the category Z-1+Z-2+Z-3. With the recovery rate 90 % for Ag and 72 % for Au and capacity utilisation of 95 %, it is realistic to obtain approximately 25.567 t of gold (resources of Z-1+Z-2 category).

Resources calculation was made using the results from exploration works carried out in years 1968-2005 (Tab. 5).

Tab. 5. Review of performed exploration works.

Organization	Sampling year	Technical works type	Technical works quantity	Sample type	Total number of samples
Kremnica GOLD, a.s.	2005	RC – wells	41 pieces	Bore cuttings	3,988
	2005	Surface furrows	9 pieces	Surface manual cuts	316
Argosy Slovakia, s.r.o.	1996-1997	Surface core holes	65 pieces	Bore core	8,604
GP SNV – GO B.B.	1968-1970	Undergr. core holes	Šturec tun. 12 pieces	Bore core	272
	1988 - 1992	Undergr. core holes	Vlad. tun. 11 pieces	Bore core	315
Rudné bane Kremnica	1966-1970	Undergr. crosscuts	Ferdin. tun. 3 pieces	Underground manual cuts	230
	1982-1985	Undergr. tunnels and crosscuts	Andrej tun. 16 pieces	Underground manual cuts	1,915
	1985-1990	Undergr. tunnels and crosscuts	Milan tun. 10 pieces	Underground manual cuts	902
TOTAL	1968 - 2005	Furrows, holes, tunnels and crosscuts	167 pieces	Bore cuttings, core, rock cuttings	16,542

The ORTAC Resources Ltd, a company focused on the exploration and development of natural resources in Europe, prepared the project of the detailed geological survey for years 2011-2012. The framework study was completed in January 2012. The ORTAC Resources Ltd., together with their daughter company, the SRK Consultants UK Ltd., examined the geotechnical, hydrological and geochemical properties of the Kremnica-Šturec deposit. The study plans the construction and operation of facilities for ore treatment together with the waste disposal sites at a single fully managed site (<http://www.ortacresources.com/>).

Resources of ore for the open-pit mine represent 13.97 Mt with the average metal content of 1.70 g t⁻¹ of Au and 14.22 g t⁻¹ of Ag (or 1.90 g t⁻¹ calculated to Au) in categories of demonstrated and probable resources (Tab. 6).

Tab. 6. Ore resources in Kremnica-Šturec classified in accordance with the JORC Code (2004) – SRK, April 2013.

Resources category	Tons (kt)	Density [t.m ⁻³]	Metal content			Content of metals (in thousand ounces)		
			Au [g.t ⁻¹]	Ag [g.t ⁻¹]	AuAg [g.t ⁻¹]	Au (koz)	Ag (koz)	Au Eq (koz)
Measured	3,084	2.17	1.62	13.05	1.80	161	1,294	184
Indicated	10,881	2.24	1.73	14.55	1.93	604	5,091	689
Total	13,965	2.23	1.70	14.22	1.90	765	6,385	873

Note: The calculation for Au (Au Eq) is determined upon the price of gold 1,350 US\$/oz, in the average recovery rate of 92%, and the price for silver 25 US\$/oz, in the average recovery rate of 65%.

Mineral resources are based on the prognostic mineral resources P-1 and P-2 for the open-pit mine, as calculated by the Snowden Company (Tab. 7).

Tab. 7. Prognostic mineral resources in Kremnica-Šturec with a marginal sample of 0.40 g.t-1 Au. Classified according to the JORC Code (2004) – Snowden, April 2012*.

Prognostic resources category	Tons [kt]	Density [t.m ⁻³]	Metal content			Content of metals (in th. ounces)		
			Au [g.t ⁻¹]	Ag [g.t ⁻¹]	Au Eq [g.t ⁻¹]	Au (koz)	Ag (koz)	Au Eq (koz)
P-1	3,000	2.17	1.69	13.50	1.96	161	1,291	187
P-2	12,400	2.24	1.76	15.20	2.07	702	6,044	823
P-1+P-2	15,400	2.23	1.75	14.90	2.05	863	7,335	1,010
Inferred resources**	9,700	2.33	0.89	5.10	0.99	279	1,587	310
Total	25,100	2.27	1.42	11.10	11.64	1,141	8,922	1,320

Notes:

*Resources in the open-pit mine are defined by the economical spatial limitation with the marginal sample of 0.26 g/t of gold.

Metal content values calculated for Au (Au Eq) are calculated based on the silver-gold ratio of 50:1.

Prognostic mineral resources include mineral resources.

**Slovak Decree No. 6/1992 Coll. to the Geology Act does not define the P-3 category of prognostic sources. In this case, it roughly corresponds to the inferred resources category, according to the classification of the reserved deposits resources

Approximately 86% of the prognostic mineral resources in P-1 and P-2 categories were moved to the categories of measured and indicated resources. The objective will be to increase the exploration rate in the category of inferred resources and increase thus the mineral resources in future.

This study shows that the Kremnica-Šturec deposit contains the economical source of gold that can be successfully processed using the technologies approved by the EU.

Conclusion

Number of geological survey works was carried out on the deposit. Resources of gold and silver containing ore, suitable for underground mining, were proved and calculated. Exploration works were carried out by bore holes from the surface. In the central and southern parts of gold and silver ore accumulation, resources of Z-1 to Z-3 categories were calculated. Drilling works were carried out mostly on lines with the distance of 100 m.

At present, the mining activities are focused on excavation of ore containing Ag and Au using the underground mining method in the Andrej tunnel. In the past, the Schrämen and the Hlavná Veins were mined within the oxidation zone also with intra-vein rashings (altered pre-silica andesites). From the technological point of view, the material - the ore can be classified as hard to process. Abrasive flint that forms a substantial part of the ore obstructs the separation. Presence of gold flakes of sub-microscopic dimensions requires high fineness of grinding (min. 90 % under the 0.074 mm) to release the electrum from the ore and separate it. These facts significantly influence treatment possibilities, especially in terms of the maximum possible recovery rate.

In the period of the deposit utilisation, several tests were carried out regarding treatability of the ore from Kremnica-Šturec, mostly in laboratories. Under the existing legal conditions, it is necessary to verify also other treatment possibilities. The Beacon Hill Consultants performed laboratory examinations of treatability of ore from deposit for the Canadian company Tournigan Gold Corp. The results were promising. Using the gravitation-flotation method they achieved the 93.9% recovery rate for gold (gold content in the sample of 2.6 g.t⁻¹). Achieved exceptional recovery rate (laboratory) will have to be proved in future in a pilot operation by processing a larger quantity of ore. A positive result would enable rational excavation of Au and Ag containing ore from Kremnica-Šturec applying the best possible environment-friendly approach.

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