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FORECASTING AND ASSESSING EUROPE'S
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WP7 Historic Mine Sites revisited

Case Study

Historic mining sites revisited – Slovenia

Focus: The Litija baryte-Pb-Zn-Hg-Ag mine

Author: Klemen Teran (GeoZS)



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Table of Contents

1	Introduction	4
2	Exploration for CRM's on historical mining sites in Slovenia	4
2.1	Litija's polymetallic mine area.....	6
2.2	Mežica polymetallic mine.....	7
2.3	Idrija mercury mine	8
2.4	Other smaller mining operations in Slovenia.....	8
2.5	Concluding remarks of CRM potential of historical mining sites.....	10
3	Obstacles for the exploitation	11
4	The Litija baryte-Pb-Zn-Hg-Ag mine case study	12
4.1	Introduction.....	12
4.2	Geological Setting	13
4.2.1	Regional geology	13
4.2.2	Deposit geology.....	14
4.2.3	Ore types and their mineralogy	18
4.3	History of Litija mine.....	19
4.4	Environmental impact.....	21
4.5	Mining wastes on the area of Litija historical mining site.....	22
4.5.1	Volume re-evaluation.....	23
4.6	Fieldwork	26
4.6.2	Sample preparation and chemical analyses.....	31
4.7	Evaluation of the Litija CRM potential.....	34



1 Introduction

During the evaluation of the potential for CRM occurrences in Slovenia, the following four critical raw materials have been identified as being the most prospective: bauxite, antimony, baryte, and with some additional consideration magnesium.

Among the above-mentioned raw materials in Slovenia bauxite is considered to be the most promising one because it is not only the preferred source of Al but can also contain other CRM elements such as REEs, germanium, scandium, etc. Apart from this, bauxites have already been mined in Slovenia in the past and several mineralised zones of bauxites exist.

The next critical raw material worth exploring in Slovenia is baryte as one of the old mines Sitarjevec is still expected to contain reasonable amounts of this ore and future exploration in the most promising region of Sava folds might help us to find new undiscovered ore bodies in this area. Exploration programs that would target this CRM need to focus especially on greater depths which have in the past not been researched enough.

Antimony is also one of the elements with potentials, especially since it was also successfully mined in the past and again exploration in deeper parts of mineralised zones would be beneficial since not much information regarding its concentrations and amounts in deeper parts is available.

Since almost half of the Slovenian territory is made of carbonate rocks, among which there is lots of dolomite (especially common are dolomites exposed on the surface of Anisian age and are also of the right thickness), there is a big potential for the exploitation of dolomite as raw material for the production of magnesium. It is essential to define areas that have the right quality and quantity of this rock.

2 Exploration for CRM's on historical mining sites in Slovenia

Slovenia has a vast mining history with some mineral exploitation operations dating back to Roman times. Due to favourable geological settings (Slovenia being on a very tectonically active area) numerous mineralisation occurrences have been recorded and many mine sites were developed throughout time. Figure 1 presents CRM occurrences in different historical mines across Slovenia. The biggest potential of CRMs is within historical mining sites developed within the Southern Alps (Pb-Zn, Sb, and bauxite mines) and within the Sava folds transition zone, where Pb-Zn, baryte, and Sb deposits were identified.

Historical mining sites in Slovenia that show CRM potential belong mainly to the Carboniferous (Variscan) and Middle Triassic (Alpine) metallogenic events. Ore deposits of Carboniferous age are Litija, Pleše, and Trojane in the Sava folds transition zone and Savske jame in the Southern Alps. As middle Triassic ore deposits can be treated Mežica in Eastern Alps, Knapovže, Lepa Njiva,



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Puharje and Zavrh in the Sava folds Transition zone and Idrija in Dinarides. Kope skarn ore deposit in Eastern Alps is younger and is connected with Tertiary intrusion of diorites.

Bauxites in the Southern Alps (Bohinj-Rudnica, Kamniška Bistrica, Kokarje, and Vranja Peč) are also of Tertiary, more precisely Oligocene age. Other parts of Slovenia, especially Dinarides contain many more bauxite deposits of the Triassic, Jurassic, and cretaceous age, but those deposits were never developed into mines.

The biggest challenge regarding identifying CRM elements in previously discovered orebodies in Slovenia is in the lack of information resulting from poor chemical analyses which were performed on most of the old mines and other mineral-perspective locations. The other problem is that the researchers in the past focused mainly on the shallower lying deposits and not so much on the deeper lying ones. Therefore, a more detailed investigation regarding the CRM occurrences in Slovenia is needed which would also include re-assaying of samples from the old mine sites, utilisation of non-invasive methods, such as geophysical and geochemical exploration tools, and finally, if any perspective anomalies are to be identified, perform some additional exploration drilling (including deep-hole drilling).

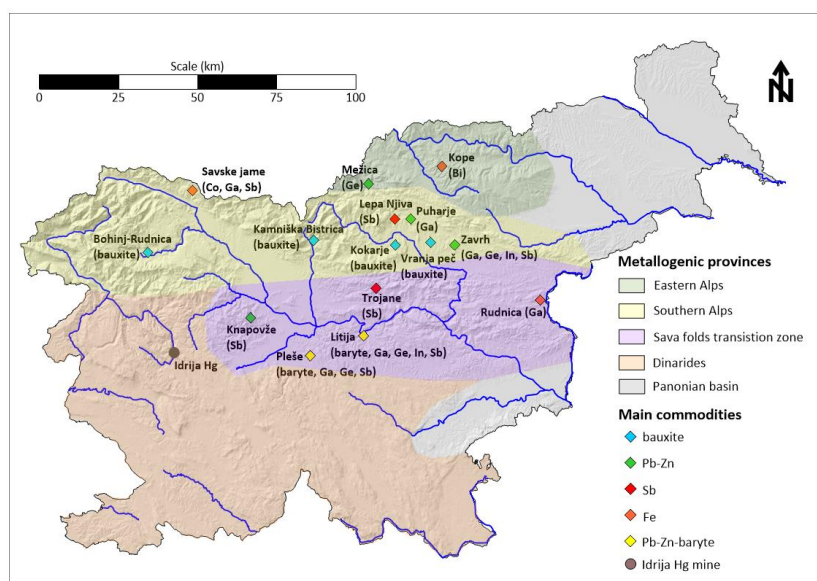


Figure 1: CRM occurrences in historical mines in Slovenia

In the following text, we will first briefly describe the possibility of holding CRMs in the three biggest metal mining areas in Slovenia (which throughout time produced reasonable amounts of ore), followed by the evaluation of other smaller mining operations.



The three biggest mining operations on the territory of Slovenia were the Idrija Mercury mine situated in the western part of the country, the Litija mines in the central part of Slovenia associated with the Sava folds (a triangular-shaped transition zone between the Dinarides, the Pannonian Basin and the Southern Alps), and the mining district of Mežica located in the Eastern Alps near the Slovenia-Austrian border. Apart from these major mines, more than a dozen smaller operations also operated in Slovenia which have the potential to host CRMs. Slovenia currently does not have any active metal mines.

2.1 Litija's polymetallic mine area

The biggest potential for discovering CRM elements in an old historical mine area in Slovenia is in Litija's polymetallic mine Sitarjevec. This baryte-Pb-Zn-Hg-Ag mine which at the end of the 19th century supplied about 10% of the annual Pb Austro-Hungarian Empire production and produced a total of 50,000 t of Pb, 30,000 t of baryte, 42,5 t of Hg, and 1 t Ag. Although the mining activity around this area speculatively began already in the Roman era, the first written documents of ore extraction in Sitarjevec are from 1537 and lasted (with several intermissions in between) until 1966.

Baryte-Pb-Zn-Hg-Ag mineralization on the Sitarjevec Hill is the most substantial of nearly 20 identified mineral occurrences on approximately 10 km² large Litija ore field, which is part of the Sava Fold Metallogenic Belt characterized by hydrothermal Zn, Pb-Zn, Pb-Zn-Hg-baryte, and Sb ore veins. The most important ore minerals are galena and baryte, followed by sphalerite and cinnabar. Other ore minerals found in the ore bodies are bournonite, cerussite, chalcopyrite, hematite, realgar, pyrite, siderite, and tetrahedrite (Drovenik et al., 1980). Gangue minerals in veins are represented by calcite, dolomite, and quartz

Table 1: Elemental levels of trace elements in galena, sphalerite, and cinnabar from Litija ore deposit. Adapted after Drovenik et al. (1980)

Element [mg/kg]	average levels in galena	average levels in sphalerite	average levels in cinnabar
Ag	4.5	-	-
Co	-	120	-
Ga	-	180	-
Ge	-	45	-
In	-	23	-
Sb	540	151	-

The mineralized zone on Sitarjevec Hill covers approximately 18 hectares. The length of the ore veins is up to 250 m, while their vertical extension does not exceed 150 m. The Litija mine has



the highest estimated mineral resources of baryte among all Slovenian ore deposits. Data that include levels of trace elements in the ore from the Litija mine are scarce. Spectral analyses of 5 galena samples, 3 sphalerite samples, and 2 cinnabar samples were performed by Drovenik (1972). Average levels of selected elements are shown in Table 1; galena from the Litija mine contains a significant amount of Ag and Sb, while sphalerite in Litija ore indicates the presence of Co, Ga, Ge, and In.

However, additional geochemical data were needed to be obtained to confirm the potential of the Litija ore deposit, particularly concerning the mining waste deposits. The average grades of ore bodies that remained unexploited are estimated to be 2.96 % Pb, 20.16 % BaSO₄, and 0.1% Zn (Fabjančič, 1965).

According to Berce (1957), the quantity of mining waste material of Litija mine is estimated at 132.300 t with 1.97 % Pb and 0.48 % Zn. The content of baryte has not been measured, but it is probably the most common ore mineral deposited on mine waste deposits. In particular, mine waste deposits from mining periods before the first extraction of baryte from ores (1941) may contain high levels of baryte.

Mining waste material is probably the most perspective material for further analysis in the Litija area, as (1) it is easily accessible, (2) it is not recultivated and represents a significant environmental burden, and (3) it could contain high baryte contents, as baryte was only mined after 1941. Mining waste deposits consist of different materials - some contain waste from mechanical separation plants, while other deposits consist of low-grade ore or material considered barren.

The potential for the discovery of higher-grade ore bodies in Litija or its surroundings is considerable, as modern exploration approaches (including geophysics and drilling) have been very limited in this area. The tectonic setting of the area implies that new ore bodies could be discovered both laterally and vertically below the currently known ore bodies. Unfortunately, the majority of the underground adits are inaccessible, which limits the collection of new geochemical data from ore vein intersections.

2.2 Mežica polymetallic mine

The polymetallic mine in Mežica is situated in the top northern part of Slovenia close to the Austrian border. It is genetically related to the Bleiberg, Raibel, and Salafossa mineralization. In the surrounding area of Mežica mine are also a few smaller metal mines and known mineral occurrences, forming the Mežica orefield.

In its 300-year mine life, the mine in Mežica produced app. 19 million tons of lead and zinc ore (Vreča et al. 2001). It ceased operation in 1993 due to the deposit becoming uneconomic for



exploitation. Apart from galena and sphalerite, there are also numerous other minerals found in the mine and its surroundings: pyrite, marcasite, barite, fluorite, wurtzite, arsenopyrite, and molybdenite, oxidized rocks also consist of smithsonite, gypsum, hydrozincite, limonite, wulfenite, and others (Drovenik and Pleničar, 1980). The orebody is hosted by carbonate rocks from the Triassic period, mainly of the Ladinian and Carnian age. Regarding ore genesis, in the Mežica mining area different types of mineral deposits can be found (eg. ore body Topla is of syngenetic origin, while most of the orebodies in Mežica belong to the epigenetic Mississippi valley type deposits).

During the initial exploration of the deposit and further ore delineation studies, the chemical analyses of samples collected in and near the ore bodies were mainly focused on the main elements of interest hence the information regarding the occurrences of CRMs are scarce. The critical raw materials from the CRM list that were recorded from the Mežica deposit are antimony, baryte, and germanium, however, the information regarding the amounts and localities is very limited. As with other known mineral occurrences in Slovenia samples from this and the surrounding deposits would need to be re-assayed.

2.3 Idrija mercury mine

Among the three biggest mines in Slovenia, only Idrija mercury mine is regarded as a world-class deposit, which was in its hey days known as one of the biggest mercury operations in Europe and produced approximately 12.7 Mt of cinnabar ore and 145 000 t of Hg in its 500-year mine life. 13% of total historic world Hg production comes from Idrija. The Idrija deposit is by its origin and local tectonics an extremely complex ore body and hosts numerous different syngenetic and epigenetic types of mineralisation. As Idrija is a monometallic ore deposit and Hg is the only mineral present in economic quantities, the potential of discovering new areas with feasible quantities of CRM elements is very low. The other restriction for a more thorough exploration program is also socio-political, as the entire area was throughout the mine life exposed to heavy mercury pollution and the public acceptance of mining is low. Furthermore, the area was placed under UNESCO protection in 2012.

2.4 Other smaller mining operations in Slovenia

Among CRM's bauxites have been identified as the most promising critical raw material in Slovenia. More than 30 karstic bauxite occurrences have been found in several locations across Slovenia, with the majority belonging to the Dinaric metallogenic unit. However smaller bauxite mines were developed only on Oligocene bauxite deposits in the Southern Alps (Rudnica near Bohinj, Kamniška Bistrica, Kokarje, and Vranja Peč) due to the more favourable SiO₂ levels in comparison to the Triassic, Jurassic, and Cretaceous bauxite in the Dinarides. Vranja peč mine was closed in 1962 (Rijavec et al. 1965), while other mines were closed even before that period.



The reasons for closure were either lack of resources or relatively large amounts of SiO_2 in bauxite which made the extraction uneconomical since the ore was mainly used to produce Al (Jelenc, 1953). The majority of chemical analyses that were performed on samples from these mines were only done for the main elements of interest (main oxides) hence ore samples should be re-assayed to define the content of nowadays interesting elements (REEs, Ge, Sc, etc.). Historically mined bauxite deposits are mostly depleted of ore resources, however, a new mining exploration programme might be viable for some of the unexploited bauxite occurrences. Further mining exploration plans shall consider also environmentally protected areas as, for instance, bauxite deposit Rudnica near Bohinj is positioned in the Triglav National Park that is by law a protected habitat, and therefore any future exploitation would not be possible. Utilization of non-invasive investigation methods, such as geophysics and geochemistry in combination with regional stratigraphic research to identify productive hiatuses in carbonate sedimentation could provide positive results. Based on the results of previous studies, a potential drilling program could be designed to delineate the extent of the potential new ore lenses.

Baryte has also been found in numerous mineralised zones and smaller mining operations across Slovenia. Apart from Sitarjevec, the biggest potential for baryte in Slovenia is in the former polymetallic mines of Pleše, where the mineralisation is also associated with Carboniferous clastic rocks. Baryte ore from the Pleše deposit is of higher quality as it contains more baryte and less iron and silica in comparison to the Litija. In Pleše apart from the two critical raw materials baryte and antimony, germanium and gallium were also discovered as trace elements in galena and sphalerite. Historical records also indicated that minor baryte mineralization was found in the Cu-Pb-Ag deposit Remšnik but the results of chemical analysis from samples from this deposit show that Ba has not been assayed. According to Fabjančič's report from 1965, baryte was detected also in several Pb-Zn deposits in central and NW part of Slovenia which were developed in small-scale mines. Štucl and Kluge (1991) also mentioned the occurrence of baryte minerals in the Kope skarn iron ore deposit. The most promising region for finding new baryte deposits in Slovenia is therefore the Sava folds transition zone, where future exploration programs should focus on known areas where mineralisation occurs also in greater depths.

Antimony has been mined from hydrothermal veins hosted by Carboniferous black shales of the Sava folds in the Trojane-Znojilje area in the beginning of the 20th-century antimony, where they have extracted approximately 4000 t of antimony. The second deposit, where antimony occurs as the main ore mineral in a hydrothermal-metasomatic ore deposit, is Lepa Njiva which is located in the northern part of Slovenia in the Southern Alps. In the Lepa Njiva deposit, the CRM element germanium has also been identified. According to old records, some 10 tonnes of antimony has been mined from this orebody. Sb also often occurs as a trace element in polymetallic sulphide deposits, therefore the potential for its exploitation also exists in some of the Pb-Zn-Cu deposits, such as Knapovže, Litija, Pleše, Puharje, Savske jame and Zavrh. In the Fe deposit, Savske jame CRM elements cobalt and gallium have also been identified in association with Pb and Zn minerals, and in Zavrh apart from CRM antimony, germanium, gallium, and



indium were also found. The other deposits where gallium has been detected are the Rudnica deposit situated also within the Sava fold transition zone and the Puharje deposit in the Southern Alps. Further research would need to be conducted to better define the amounts of antimony and other CRM elements within these deposits and pre-feasibility studies would afterward indicate if any future extraction could be economically justifiable.

Although dolomite is already mined in numerous locations around Slovenia as technical rock, the quality and chemical purity of the material mined in these quarries are questionable. If there would be interest to mine dolomite for magnesium production, new deposits with pure dolomite would need to be discovered. The potential for discovering economically feasible amounts of material of the right quality is believed to be big.

2.5 Concluding remarks of CRM potential of historical mining sites

Although Slovenia has a vast mining history and the geological settings are favourable to host rich mineralised zones (Slovenia being on a very tectonically active area), the potential of finding reasonable amounts of any CRM elements in historical mines is limited. The four CRM's that have been recognised as the most potential (bauxite, baryte, antimony, and magnesium) occur in historical mine sites which were mostly closed not because they extracted all of the known ore reserves, but mainly because of the economic viability of the operations during their closures. Information regarding CRM elements in these deposits is limited and most of the ore bodies are due to a lack of data still considered to be open down deep and down plunge. Also, chemical analyses from the old reports show that most of the time CRM elements were not assayed. For a more in-depth assessment of CRM potential in the territory of Slovenia the following tasks are proposed:

- Re-assaying of samples from old mining areas (the chemical analyses need to include CRM elements).
- Conduct thorough studies of the genesis of old ore bodies, including deep hole drilling which would penetrate through all the lithological sequences of the orebody.
- Utilize modern mineral exploration techniques (geophysics, geochemistry) in the exploration investigations.
- If any anomalies are identified perform exploration drilling (RC and/or diamond (core) drilling).
- If any potential targets are discovered conduct an infill drilling program to delineate the geometry and volume of the orebody.
- Conduct a pre-feasibility study of the potential deposit which would suggest if the deposit would be economically feasible.

It can be concluded that the most prospective CRM to be researched in Slovenia are bauxites, mainly because there are many known occurrences of this material, it has already been mined in Slovenia in the past and besides being the preferred source of Al it can also contain other CRM



elements. For this purpose, geochemical analysis of bauxites is needed. Baryte and antimony are also potential materials, it is believed that the focus should be on better defining the amounts still left in the old mines around Litija and Trojane, especially in greater depths. Because almost half of Slovenian territory is composed of carbonate rocks, there is a big potential for the exploitation of dolomite as raw material to produce magnesium. The challenge of future exploration of magnesium deposits in Slovenia is to discover areas that have the right quality and quantity of this rock to be economically mined.

3 Obstacles for the exploitation

As already stated, a significant obstacle for CRM exploitation in Slovenia is the lack of data on their grades as well as the absence of any modern exploration campaigns.

Furthermore, social acceptance of mining in Slovenia is low. The main reason for that is strong pollution of the environment around historical mines and metal smelters which was caused either due to the absence of emission filters in the smelters, inappropriate practices of mining waste deposition in historical mines, or both. Exceedance of topsoil critical values for at least one element caused by historical mining and smelting was detected on 24 km² around Litija baryte-Pb-Zn-Hg-Ag mine (Šajn and Gosar, 2007), on 24.4 km² for Mežica Pb-Zn-Mo mine, on 21 km² for Idrija Hg mine, and 17.7 km² around Celje Zn smelter (Šajn and Gosar, 2004). A lot of efforts are therefore needed to obtain a social license to operate for any kind of mineral extractive industry.

An obstacle for the revitalization of the mining activities is also limited access to the mining sites or mining waste deposits due to the urbanization and/or remediation of some mining sites. Urbanization of the mining sites, especial mining waste deposits can be observed in Litija, where some of the mining offices were built on the old mining waste deposits and after the closure of the mine transformed into apartment buildings.

Parts of the several historical mines, namely Idrija, Mežica, and Litija, were transformed into the visitor's mine museums. In Idrija and Mežica were also established Geoparks and Idrija was listed under UNESCO protection of cultural heritage. All such development is of course very welcomed for the revitalization of the former mining areas and growth of cultural awareness, but it limits access to the ore deposits in case of potential future exploitation.

A potential limiting factor for the exploitation of CRMs is also Natura 2000 or other national laws (national and regional parks). Areas of historical mines in Slovenia that were active for long periods and closed down after 1960 are largely outside such protected areas (mainly due to the degraded environment). However, some of the other smaller historical mining sites which were closed at the begging of the 20th century or earlier can be contained in such protected areas (Rudnica near Bohinj for instance).



4 The Litija baryte-Pb-Zn-Hg-Ag mine case study

4.1 Introduction

Litija Pb-Zn-Hg -baryte mine (also known as Sitarjevec) was one of the most important metal mines on Slovenian territory. At the end of the 19th century, it supplied about 10% of the annual Pb Austro-Hungarian Empire production and produced a considerable amount of Ag. Underground ore mining is documented from 1537 to 1966 with several periods of inactivity.

The Litija mine is located in the central part of Slovenia on the banks of the Sava River, 40 km E from the capital Ljubljana (Figure 1). Mineralization in Litija is hosted by hydrothermal polymetallic ore veins intersecting Carboniferous sandstones, conglomerates, and black shales formed during the Hercynian orogeny phase. The main ore minerals are galena and baryte, followed by sphalerite and cinnabar.

The mineralized zone on Sitarjevec Hill covers approximately 18 hectares. The length of the ore veins is up to 250 m, while their vertical extension does not exceed 150 m.

The Litija mine has the highest estimated mineral resources of baryte among all Slovenian ore deposits. Besides, galena from the Litija mine contains a significant amount of Ag and Sb, while existing multielement chemical analyses of Litija ore indicate the presence of Co, Ga, Ge, and In. However, additional geochemical data still need to be obtained to confirm the potential of the Litija ore deposit, particularly concerning the mining waste deposits.

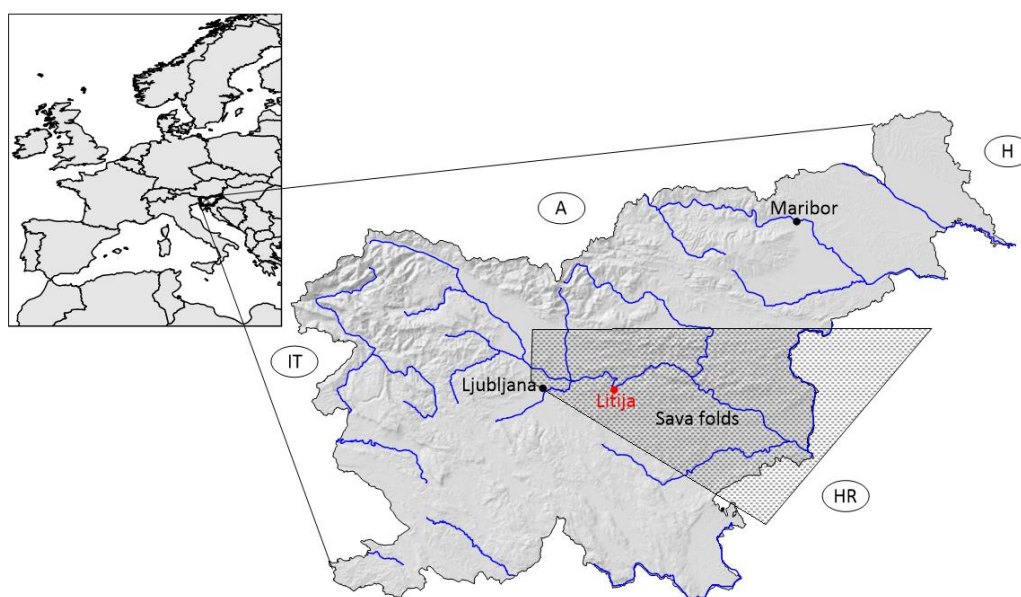


Figure 2: Geographic position of Litija within Slovenia. Black polygon represents an area of the Sava folds structural unit.



4.2 Geological Setting

4.2.1 Regional geology

The wider area of Litija in a structural sense belongs to the Sava folds – a triangular-shaped transition zone between the Dinarides, the Pannonian Basin, and Southern Alps (Figure 2) (Placer, 2008). Junction of the three major structural units is a reason for the complex structure of the Sava folds, which consists of the nappe overthrusts of Dinaric provenience (overthrust towards the SW in Oligocene and Early Miocene), which were subsequently folded in the Late Miocene due to the Southern Alps overthrusts (Placer, 2008). Folds extending in a W-E direction consist of 14 large anticlines and synclines. Litija belongs to the central part of the Litija anticline. The area of the Sava folds is intersected by several large strike-slip faults, mostly in the NW-SE direction (also called "Dinaric faults"), which caused dextral slip of the tectonic blocks in the post-Miocene period. Some of them are still active and have recently caused seismic activity.

The oldest rocks exposed in the centre of the Litija anticline are Carboniferous clastic rocks, which were sedimented in the deltaic-fluvial environment during Hercynian orogeny (Figure 3) (Mlakar et al., 1992). Clastic rock sequences are represented by quartz conglomerates, quartz and mica sandstones, and siltstones as well as a dark grey to black shales. Carboniferous clastic rocks host Pb, Zn, Cu, Hg, and baryte hydrothermal vein mineralization, which occurs most frequently in quartz and mica sandstones. Sedimentation was interrupted in the Late Carboniferous due to the strong tectonic phase.

The rocks of the Carboniferous are unconformably overlaid by reddish and yellowish mica sandstone from the Lower Triassic with intercalations of oolitic limestone and stratified dolomite, concordantly followed by Anisian dolomite. Lower Triassic rocks were deposited in the shallow Slovenian Carbonate Platform (Dozet & Buser, 2009). As a result of the Middle Triassic extensional tectonic regime, the carbonate platform disintegrated into trenches and blocks, accompanied by volcanic activity. The Ladinian rocks in the wider area of Litija consist of dark grey to black platy limestone with chert, black microsparite dolomite with chert, and grey to greenish tuffs, which were deposited on Lower and middle Triassic beds after hiatus in sedimentation. The Ladinian rocks are overlaid by Lower Carnian dolomite. The youngest rocks of the area are Pliocene-Quaternary and Quaternary Sava River sediments that cover river valleys, depressions, and foothills.

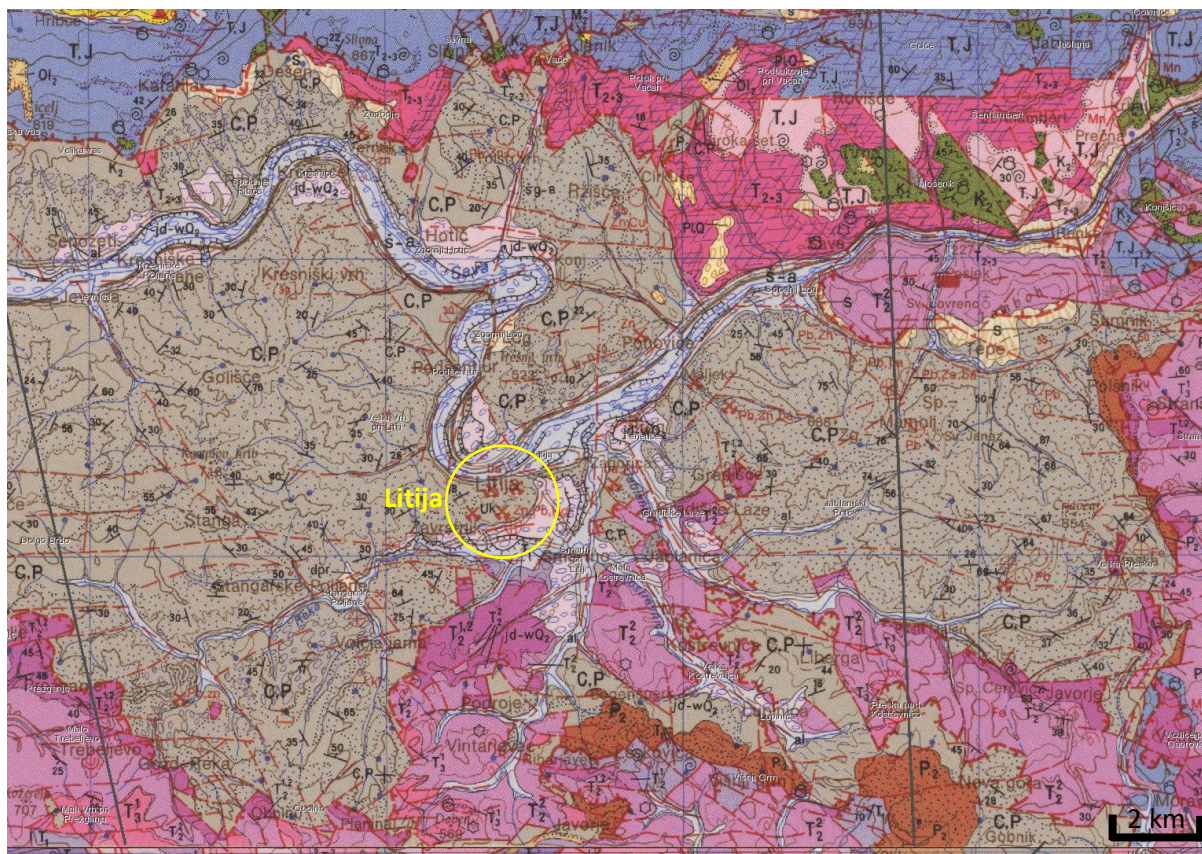


Figure 3: Geological map of wider Litija area (original scale of map 1:100,000). Carboniferous rocks (grey pattern) are exposed in the centre of Litija anticline (source: <https://ogk100.geo-zs.si/>).

4.2.2 Deposit geology

Pb-Zn-Hg -baryte mineralization on the Sitarjevc Hill in Litija is the most substantial of nearly 20 identified mineral occurrences on approximately 10 km² large Litija ore field, which is part of the Sava Fold Metallogenic Belt characterized by hydrothermal Zn, Pb-Zn, Pb-Zn-Hg -baryte and Sb ore veins.

The ore bodies of the Litija ore field are hosted by Carboniferous clastic rocks, which are exposed in the central part of the Litija anticline. Sandstones, which are the most common lithological unit in the Litija area, consist of up to 0.5 mm large grains of quartz, muscovite, biotite, chlorite, calcite, pyrite, bituminous matter, and lithic fragments such as quartzite and black shales bonded by the sericite, organic material and accessory minerals in the matrix (Drovenik and Pleničar, 1980). Conglomerates have a similar mineral composition to sandstone, with a slightly higher proportion of quartzite and chert fragments at the expense of quartz and muscovite. Black shales consist of quartz, sericite, bituminous material, and illite.



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Mineralization occurs in discordant and concordant ore bodies with NW-SE strikes and dips ranging from 30 to 70° towards NE. Concordant ore bodies can have a sub-horizontal orientation. The majority of the approximately 40 ore bodies explored on Sitarjevec Hill are hosted by sandstones.

Discordant ore bodies are 0.05 to 1 m wide hydrothermal veins (Figures 4 and 5) with an asymmetrical structure. Higher temperature minerals formed vein edges, while the central part of the veins was formed of lower temperature minerals. Vertical zoning of discordant ore veins was also observed - the apical parts of the veins were dominated by baryte, galena, and cinnabar, while deeper parts of the veins contained more sphalerite and quartz.

Concordant ore bodies "Alma" are massive ore lenses with an average thickness of 2 m and a cumulative dimension of 550x270 m, which are explored only in the upper part of the Sitarjevec Hill. Their formation was either a consequence of the exhalation of hydrothermal fluids at the surface (SEDEX type) (Herlec et al., 2004) or a selective hydrothermal-metasomatic replacement of the highly bituminous sandstone bed. (Mlakar, 1993). They show asymmetric zonation, with baryte as the main ore, while galena, cinnabar, limonite, and hematite are present in the upper part of the ore body.

The Litija mineralization was formed in the Carboniferous during the Hercynian orogeny. In case the concordant ore bodies belong to the SEDEX type, the mineralization can be assumed to be syngeneic with the host rocks dated in the lower part of Upper Carboniferous (Kolar-Jurkovšek and Jurkovšek, 2019). If all ore bodies are epigenetic, the ore was formed at the end of Carboniferous.



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Figure 4: Discordant baryte-galena ore vein in »Main Transport Adit«



Figure 5: Approximately 1 m wide Baryte ore vein in the »Main Transport Adit«

The geological setting of Sitarjevec Hill shows a flat synclinal structure with gently dipping or subhorizontal layers of sandstone, black shales, and conglomerates (Figure 6). Three tens of meters thick black shale horizons were discovered within the ore deposit. Most of the ore bodies, including very rich concordant ones were discovered in the uppermost part of the ore deposit, above the third black shale horizon (Figure 6). However, the contact between the third black shale horizon and the overlying sandstones has an overthrust character, which explains why the ore bodies above the third black shale horizon do not extend below it. The origin of the nappe and the distance of the displacement is not known. Nevertheless, discordant ore veins were found and exploited even under the third black shale horizon. The confirmed vertical span of mineralization is 400 m. Some displacement of rocks and ore bodies was also caused by post-Miocene NW-SE striking dextral strike-slip Dinaric faults.



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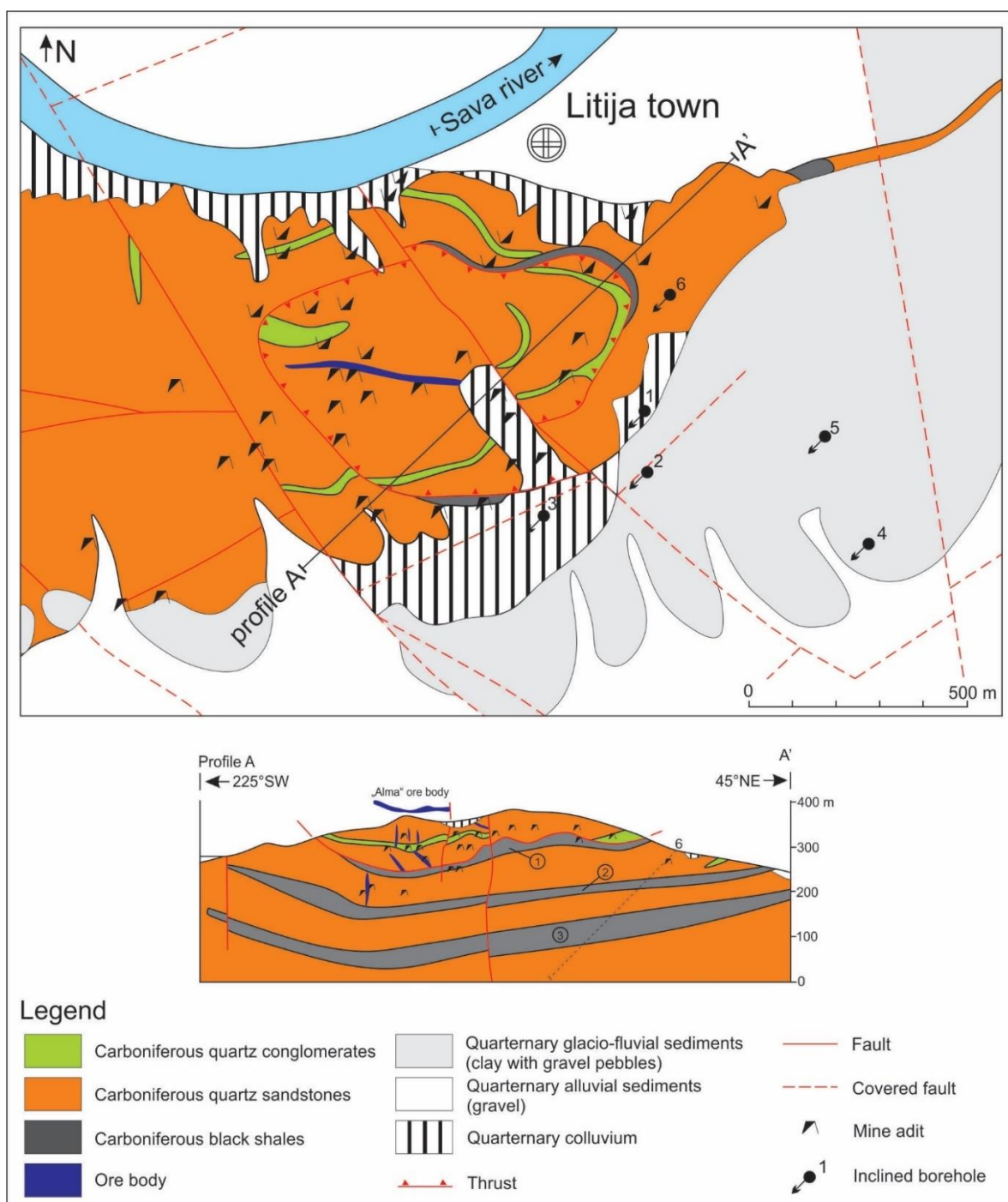


Figure 6: Lithological and structural map of the area of Litija historical mine with a representative cross-section. The map is adapted after Mlakar (1994).



4.2.3 Ore types and their mineralogy

The most important ore minerals are galena and baryte, followed by sphalerite and cinnabar. Other ore minerals found in ore bodies are bournonite, cerussite, chalcopryrite, hematite, realgar, pyrite, siderite, and tetrahedrite (Drovenik and Pleničar, 1980). Gangue minerals in veins are represented by calcite, dolomite, and quartz. The mineral composition of the host rock was discussed in the previous chapter.

The average grades of ore bodies that remained unexploited are estimated to be 2.96 % Pb, 20.16 % BaSO₄, and 0.1% Zn (Fabjančič, 1965). Data that include levels of trace elements in the ore from the Litija mine are scarce. Spectral analyses of 5 galena samples, 3 sphalerite samples, and 2 cinnabar samples were performed by Drovenik (1972). Average levels of selected elements are shown in Table 2:

Table 2: Elemental levels of trace elements in galena, sphalerite, and cinnabar from Litija ore deposit. Adapted after Drovenik et al. (1980)

Element [mg/kg]	average levels in galena	average levels in sphalerite	average levels in cinnabar
Ag	4.5	-	-
Co	-	120	-
Ga	-	180	-
Ge	-	45	-
In	-	23	-
Sb	540	151	-

It has been estimated that mining waste material contains about 1.97 % Pb and 0.48 % Zn (Berce, 1957). The content of baryte has not been measured, but it is probably the most common ore mineral deposited on mine waste deposits. In particular, mine waste deposits from mining periods before the extraction of baryte from ores may contain high levels of baryte.

Mining waste material is probably the most perspective material for further analysis in the Litija area, as (1) it is easily accessible, (2) it is not recultivated and represents a significant environmental burden, and (3) it could contain high baryte contents, as baryte was only mined after 1941. Mining waste deposits consist of different materials - some contain waste from mechanical separation plants, while other deposits consist of low-grade ore or material considered barren.

The potential for the discovery of higher-grade ore bodies in Litija or its surroundings is considerable, as modern exploration approaches (including geophysics and drilling) have been very limited in this area. The tectonic setting of the area implies that new ore bodies could be discovered both laterally and vertically below the currently known ore bodies. The majority of



the underground adits are inaccessible, which limits the collection of new geochemical data from ore vein intersections.

4.3 History of Litija mine

Archaeological sites near Sitarjevec Hill indicate that mining was carried out in Litija 4000 years ago. Remains of dwellings and slag from that time have been found at the location of the Litija Primary School and on the Sitarjevec hill. The natives collected the ore from the surface outcrops. It is speculated that underground mining was already active in Roman times.

Litija became an important mining center in the 16th century, and consequently, a higher mining office was established in Litija. The mine was operated by Saxon miners. The first written document about mining in the Litija area is the gravestone for the mining master Cristof Brukerschmid from 1537, which can be seen today in the church in Šmartno pri Litiji.

Until 1542 they mainly mined iron, but since then production has concentrated on the exploitation of lead. No records have been preserved of the amount of ore mined during this period. In 1604 the mine was closed down due to a lack of capital and mining experts (Counter-Reformation period).

In 1792 an iron smelter was built near Litija. Iron ore was also sporadically mined on Sitarjevec Hill during this period. Mining exploration on Sitarjevec Hill was resumed for a short period in 1838 together with the Zavrstnik area SW of Sitarjevec.

More serious mining exploration in Litija began in 1873, which led to the exploration of the high-grade baryte-cinnabar concordant ore body "Alma". Only mercury ore was mined in 1875 and 1876. During the gradual expansion of mining to lower horizons, galena prevailed in the ore veins, and lead became the main product from 1877 onwards. In 1878 the mining company "Gewerkschaft Littai" was founded. A smelter was built in 1881 (Figure 7) and a mechanical processing plant in 1882. In 1886 smelter began extracting Ag. Around 1890, the mine contributed 10.2% of the Austro-Hungarian annual lead production. Mining in Litija was stopped in 1897 due to insufficient ore resources. The smelter, however, remained active and processed imported Pb concentrate.

The mine was revived in 1917 and was active until 1922. In 1924 the smelter was closed due to the beekeeper's complaint about air pollution. Nevertheless, mining activity was revived the same year (Figure 8), with a boost of production after the construction of the gravitational ore separation and flotation plant in 1927. The mine was closed again in 1930 due to the low metal prices on the stock markets caused by the financial crisis. In 1941, the Germans revitalized the mine and began producing baryte. Mining was stopped in 1944.



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FORECASTING AND ASSESSING EUROPE'S
STRATEGIC RAW MATERIALS NEEDS

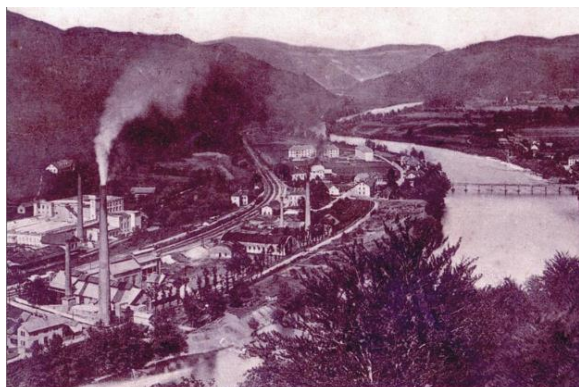


Figure 7: Smelter in Litija in 1910 (Šajn and Gosar, 2007),

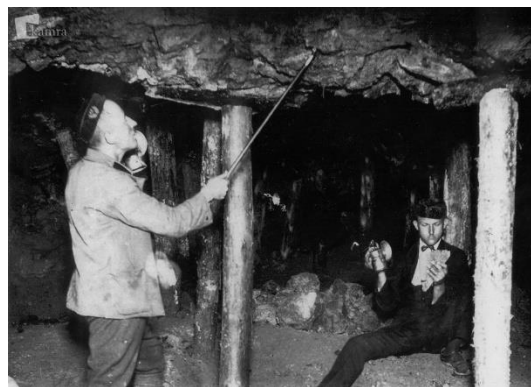


Figure 8: Miners in one of the adits within Litija mine during the year 1926 (source: Kamra, 2018)

Table 3: Production data given by Mlakar (1993).

Period	Product				
	Fe (t)	Pb (t)	Hg (t)	Ag (kg)	Baryte (t)
< 1542	unknown	-	-	-	-
1542-1604	unknown	unknown	unknown	unknown	-
1792-1873	unknown	unknown	unknown	unknown	-
1873-1879	-	unknown	8,0	unknown	-
1880-1897	-	17,812	149.738	2,785	-
1919-1944	-	6,273	-	-	2,299
1946-1965	-	4,266	-	-	29,707
Cumulative production	unknown	28,351	158	2,785	32,006

In 1947 the exploration activity was resumed. In 1951, the mine started to produce baryte, while the production of Pb ore started in 1956 after the construction of a wet mechanical separation and flotation plant. Between 1962 and 1965, seven exploration boreholes were drilled. In 1966, the Litija mine was officially closed due to low ore grades, unsuccessful exploration activities, unsuitable ore processing facilities, and problems with occupational diseases.

The historical ore production of the Litija mine is summarized in Table 3. Due to the lack of data on mining production in the period between 1537 and 1879, Mlakar (1993) estimates that the Pb production of the Litija mine can be about 50,000 t, as stated in Drovenik and Pleničar (1980).



4.4 Environmental impact

The mining and smelting activities in Litija left a strong impact on the environment. Elemental levels of Pb measured in the topsoil (0-5 cm) on the Sitarjevec Hill and in the urban area of Litija exceed action values defined in the New Dutch List (Šajin and Gosar, 2007 and 2014). The topsoil elemental levels for As, Hg, Mo, Sb, and Sn are close to the intervention limits. Anomalous elemental levels of As, Cd, Hg, Pb, Sb, Sn in Zn have also been detected in attic dust, suggesting the importance of Pb emissions from smelting plant on the environment (Jemec and Šajin, 2007).



Figure 9: Fe-sulphate-hydrates speleothems in Litija mine (Zarnik, 2018)

The lower horizons of the Litija mine also contain large quantities of water, which form acid mine drainage. Water is enriched with Pb, Cu, Hg, Ba, and S, while favourable water Eh/Ph allows the formation of Fe-rich crusts and speleothems (Figure 9) (Miler et al, 2018). However, these crusts can form dams within the adits and when such a dam collapses, water may erupt, flooding the area in front of the adit entrance. Two such events have already been recorded in Litija in 1895 and 1932 when 1600 m³ of mud flooded the old city centre of Litija (Herlec et al. 2006a).



4.5 Mining wastes on the area of Litija historical mining site

According to Gosar et al. (2020), approximately 140,000 m³ of mining waste was deposited in the Litija historical mining area in several different locations. This corresponds to the total amount of 288,000 t of deposited material, considering the specific weight of the mining waste material is 2.056 t/m³ (Berce, 1957). Average grades of Pb and Zn in mining waste material are 1.97 % and 0.48 % respectively, while BaSO₄ was never analyzed (Berce, 1957).

The majority of mining waste material is deposited on the southern slopes of the Sitarjevec Hill. Six large and several smaller mining waste deposits are visible on the LIDAR elevation model shown in Figure 10. Mining waste deposits marked as with IDs 1-5 represent deposits of low-grade ore and material which was considered barren. Mining waste deposit marked as ID 6 represents material from wet separation and flotation facility. A significant environmental impact is reported for those mining waste deposits since erosion and remobilization of the material is an important source of As, Hg, Pb, and Zn in the topsoil and water (Šajn and Gosar, 2007).

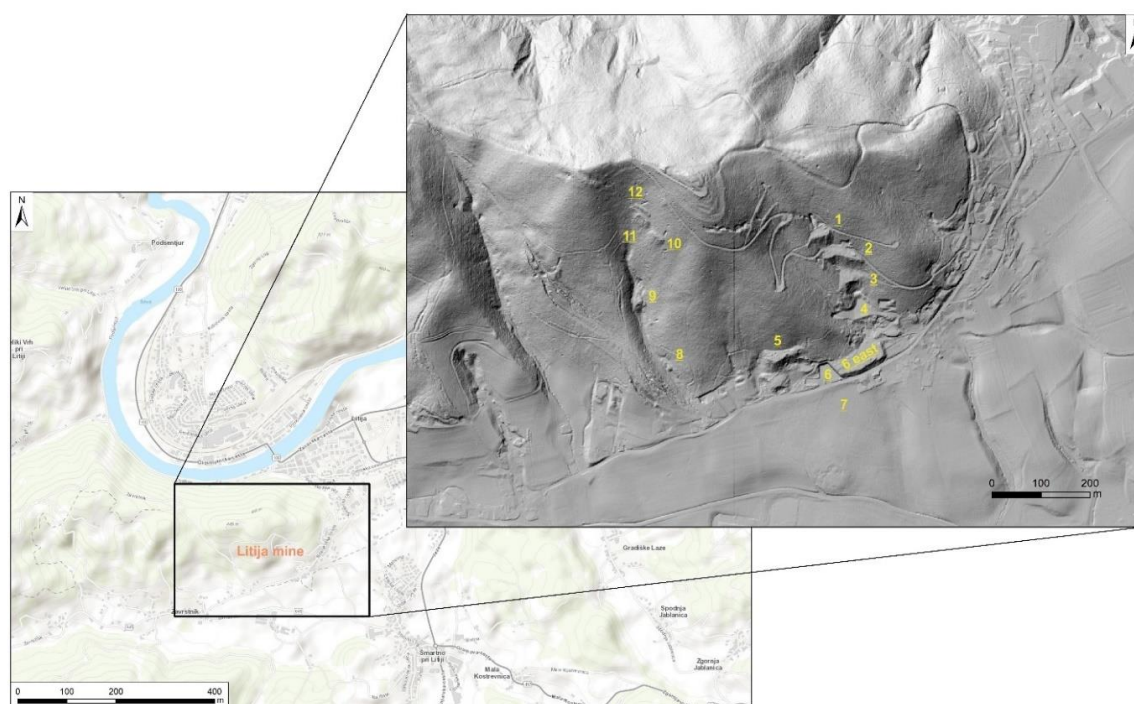


Figure 10: Map of Litija area with LIDAR elevation model of the Sitarjevec Hill, where the historical mine is located. Mining waste deposits on the southern slopes of Sitarjevec Hill are marked with number IDs (Maps source: ARSO (2020))



Gosar et al. (2020) reported the existence of another considerable mining waste deposit on the alluvial plain located south of the Sitarjevec foothill (ID 7 in Figure 10) referred to as the “Pregrada” mining waste deposit. This mining waste deposit contains approximately 20.000 m³ of material composed of fine-grained material from the flotation plant deposited between 1961 and 1965. It was partially recultivated and transformed into a meadow, which is the main reason why it is not visible on the LIDAR elevation model.

Construction of the residential buildings on the area of the former mine reduced accessibility to the mining waste deposits. Mining waste piles marked as ID 2 and ID 6-east (Figure 10) are occupied by residential buildings (some of them are renovated buildings of former mining headquarters), while mining waste deposits marked as ID 4 host the entrance into the mining museum in one of the adits. Based on the above-described observations, a recalculation of the available mining waste volumes was conducted.

4.5.1 Volume re-evaluation

Volume calculation was done using ArcMap 10.8. and SKUA-GOCAD 19 software. Boundaries of six larger and five smaller mining waste deposits visible on the LIDAR elevation model with 1 x 1 m spatial resolution (ARSO, 2020) were defined with polygons (Figures 12 and 13). To define the actual morphology of the valley, the LIDAR models of the waste piles had to be removed (Figure 11 - 1). SKUA-GOCAD was afterward used to estimate the average side valley slopes (Figure 11 - 2) and average slope of valley bottom line (Figure 11 - 3) of the mining waste deposit area. The next step was to create extended lines in the mining area based on the estimated average slopes (Figure 11 - 4). Those lines and the elevation data from the edges of defined polygons of the waste deposit areas were applied as boundary conditions for interpolation of the natural state before the deposits. The natural state surface was interpolated in ArcMap using the “Topo To Raster” interpolation method (Figure 6). Volumes were calculated by subtraction of the LIDAR model of the waste material and interpolated elevation model in a natural state. The results of the calculations are presented in Table 4.



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FORECASTING AND ASSESSING EUROPE'S
STRATEGIC RAW MATERIALS NEEDS

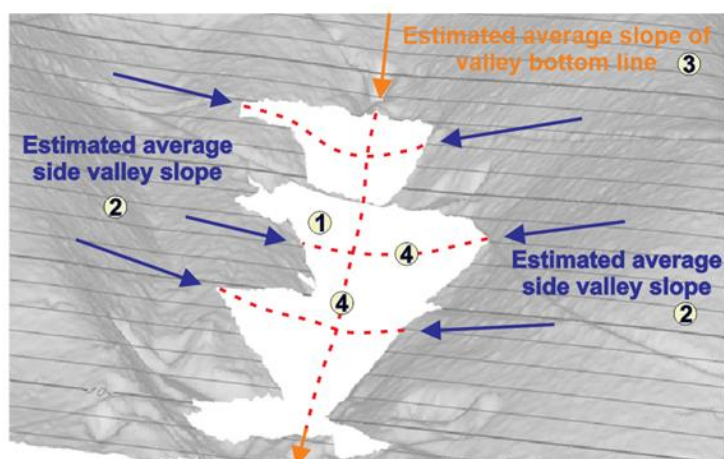


Figure 11: Graphical representation of the interpolation process of the natural ground beneath mining waste deposits

Table 4: Status, volume, and tonnage of the mining waste deposits considered in volume recalculation (Abbreviations: DL- detection limit, FUS-OS - Fusion-Inductively Coupled Plasma Optical Emission Spectroscopy, FUS-MS -Fusion-Inductively Coupled Plasma-Mass Spectrometry, CV-AA - Cold Vapor Atomic Absorption Spectroscopy.)

ID	status	Volume [m ³]	Tonnage [t]
1	accessible	3,553	7,305
2	occupied	5,319	10,936
3	accessible	6,964	14,318
4	occupied	4,032	8,290
5	accessible	14,056	28,899
6	Partially occupied	40,756	83,794
7	accessible	20,000*	41,120
8	accessible	419	861
9	accessible	2,735	5,623
10	accessible	723	1,486
11	accessible	328	674
12	accessible	316	650
6-east	occupied	22,684	46,638
SUM	total	99,200 m³	204,000 t
SUM	occupied	35,000 m³	72,000 t
SUM	accessible	64,200 m³	132,000 t

The total volume of selected mining waste material was calculated to be 79,200 m³. If we add the 20,000 m³ of “Pregrada” mining waste material (Marked as ID 7 on Figure 10), which could



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FORECASTING AND ASSESSING EUROPE'S
STRATEGIC RAW MATERIALS NEEDS

not be determined with the above-described interpolation method, we can conclude that approximately 99,200 m³ of mining wastes is deposited in the vicinity of the Litija historical mine. Calculated volume is lower in comparison to the volume listed in Gosar et al. (2020) which is based on data from historical production reports. However, it needs to be noted that the difference can be due to the usage of mining waste material as a construction material after the mine closure (as visible in Figure 10, ID 6).

Nevertheless, when considering the potential extraction of commodities, the volumes of mining waste material that is occupied with residential buildings, which are currently inaccessible need to be subtracted from the total volume. The volume of mining waste deposits occupied with residential buildings (ID 2,4 and ID 6-east – Figure 13) is 35,000 m³.

The volume of accessible mining waste material is therefore 64,200 m³. Considering the specific weight of mining waste is 2.056 t/m³ (Berce, 1957), the calculated volume corresponds to the total of 132,000 t of accessible mining waste material.

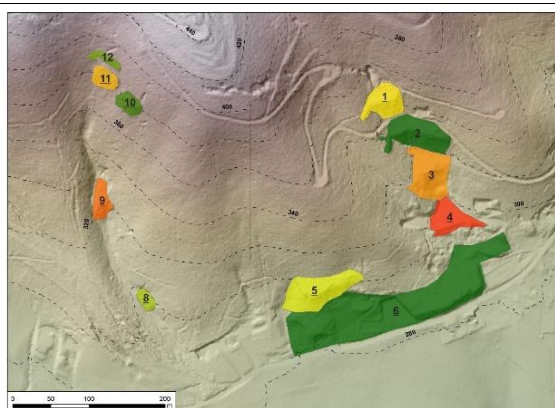


Figure 12: Mining waste deposits included in the total volume calculation (ID 1-12).

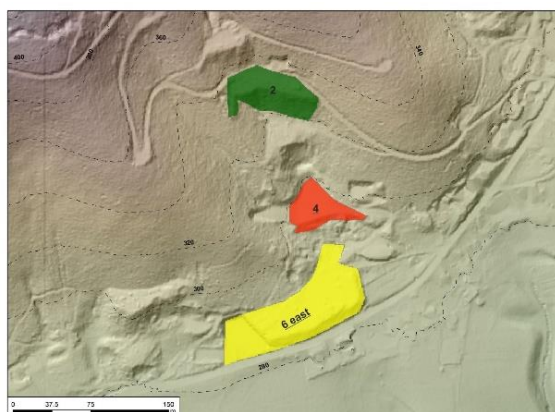


Figure 14: Mining waste deposits occupied with residential buildings. Their volumes were subtracted from the total volume

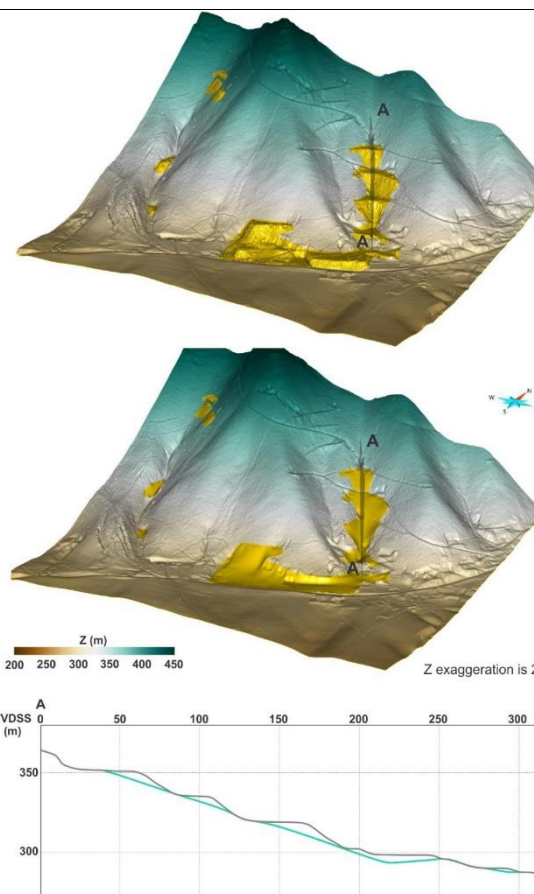


Figure 13: LIDAR elevation model before and after the interpolated natural ground beneath the mining waste deposits, together with a long section along the valley with estimated valley bottom line.

4.6 Fieldwork

After an extensive literature desk study, acquisition of new data for Litija historical mining site was focused on mining waste deposits since they are a) easily accessible, b) represent a serious environmental burden, and c) there is no existing data about their elemental composition (with the exception for Pb and Zn). The location and morphology of the mining waste deposits in Litija is showed on the LIDAR image (Figure 11). The area of the former mine is characterized by five larger mining waste deposits (Figure 15). One of them is occupied with residential buildings and therefore inaccessible for future processing. The other four were sequentially numbered from the bottom to the top of the hill and each of them was sampled separately.



Sampling was conducted in two days. On the 11th of March 2020 samples “1” and “2” were collected, while samples “3” and “4” were collected on the 16th of October 2020.

Approximately 10 kg of sample was collected from each mining waste deposit. Samples were collected from the surface of the mining waste deposits, by digging an approximately 20 cm deep hole. Each sample consisted of 10 sub-samples taken at different locations within the mining waste deposit to ensure approximate representativeness. However, the mining waste deposits were very heterogeneous - the particle size ranged from the clay fraction to fragments with a diameter of 20 cm or more. In addition, the mining waste was laminated, as the deposited material depended on the place of exploitation. The material between laminas, layers, and different parts of mining waste deposits can vary considerably. The most homogeneous structure had mining waste from the ore processing plant (part of the “Sample 1”), which was orange in colour and contained mainly sand and clay fraction. The sampling locations and sampling process is shown in Figures 12-15.

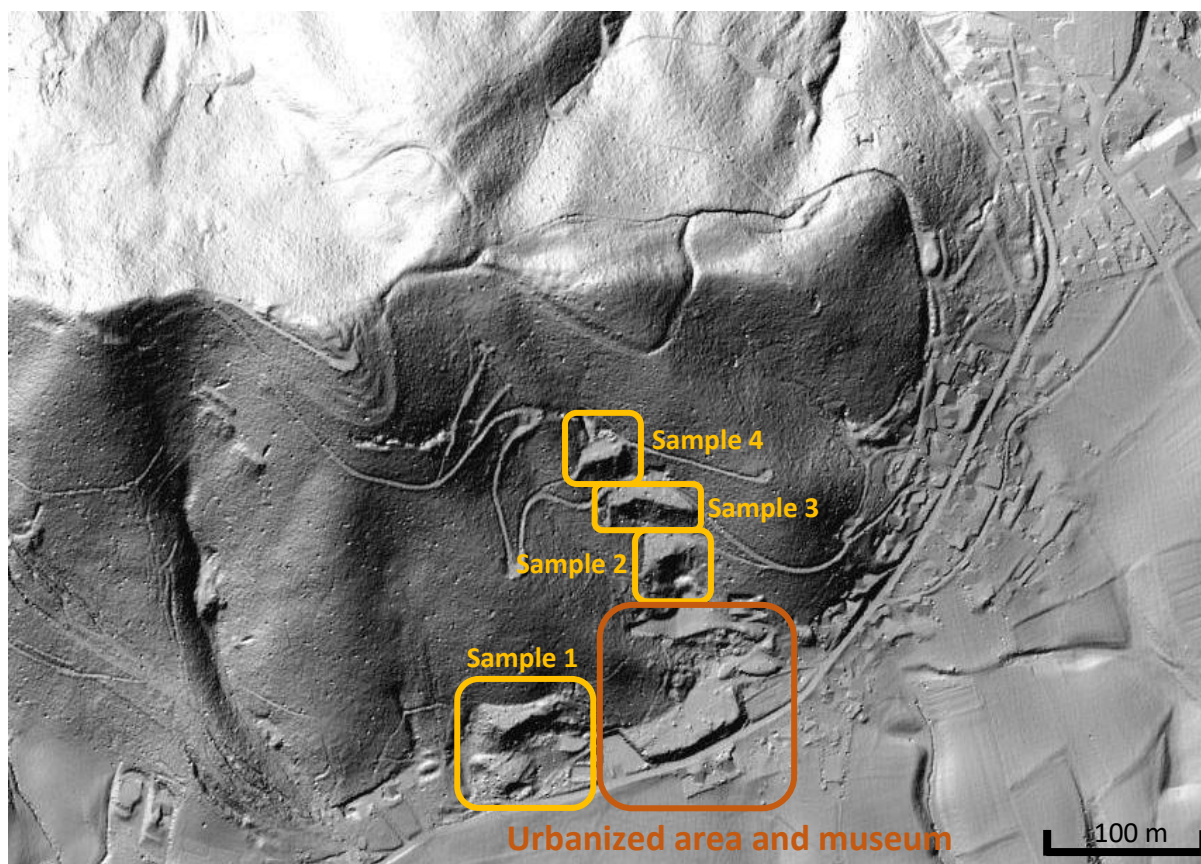


Figure 15: LIDAR image of the Sitarjevc hill (source: ARSO, Atlas okolja) with visible mining waste deposits (together with adits entrances). Sampled mining waste deposits are marked with orange colour.



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STRATEGIC RAW MATERIALS NEEDS

4.6.1.1 Sample description

“Sample 1” was represented by the combination of flotation mining waste – orange coloured material with particles in the fraction of clay and sand and waste material from the “Main transport adit” – grey to brown coloured material with rock particles ranging in size of blocks (Figure 16). Part of the material from that area is already missing since it was used as construction material in the past.



Figure 16: Material collection for the »Sample 1«

“Sample 2” was taken from the mining waste deposit above the entrance of the “Main transport adit” where is now visitors museum. The material was excavated in the “Gröll adit”. Mining waste deposit has almost now vegetation cover and is exposed to the strong water erosion. On the slopes are exposed layers of deposited material that belongs to the different lithologies (Figure 17).



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FORECASTING AND ASSESSING EUROPE'S
STRATEGIC RAW MATERIALS NEEDS



Figure 17: Mining waste deposit where »Sample 2« was taken.

“Sample 3” was taken on the mining waste deposit belonging to the “Prikopni adit” which is above “Gröll adit”. Mining waste deposit is relatively strongly covered with vegetation and partially urbanized (Figure 18).

“Sample 4” was represented by the material considered as barren in front of “Alma” adit. Alma was the thickest and the richest ore body in the Litija mine. It is considered a sub-horizontal concordant orebody, which differs from the other, discordant ore veins (Figure 19).



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STRATEGIC RAW MATERIALS NEEDS



Figure 18: Subsample locations for »Sample 3«. The first image shows a fragment of baryte on the mining waste deposit



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STRATEGIC RAW MATERIALS NEEDS



Figure 19: Mining waste deposit where »Sample 4« was taken and images of subsample locations for »Sample 4«.

4.6.2 Sample preparation and chemical analyses

Samples were transported to the GeoZS laboratories, where were air-dried at 40°C for several days. Samples were afterward crushed on 2 mm fraction, rifle split on 250 g which was then pulverized on 105 µm particle fraction.

Samples were sent to the commercial laboratory Activation Laboratories in Ancaster, Ontario, Canada where lithium metaborate/tetraborate fusion was applied for sample digestion. The resulting molten bead was rapidly digested in a weak nitric acid solution. Elemental levels were quantified for 54 elements using fusion ICP-OES, ICP-MS, and cold vapor AA (Hg only).

Results of the chemical analyses performed on bulk samples collected from mining waste deposits marked as Sample 1, 2, 3, and 4 are summarized in Table 5. Grades of baryte range between 3.9 and 14 % (median 5.1 %), while grades of Pb range between 0.1 and 1.5 % (median 0.8 %). Zn levels are very low and range between 150 and 660 mg/kg (median 250 mg/kg). The



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FORECASTING AND ASSESSING EUROPE'S
STRATEGIC RAW MATERIALS NEEDS

absence of Zn is also reflected in lower grades of CRM elements which are contained by sphalerite, such as Co, Ga, Ge, and In. Median levels of Ga are 9.5 mg/kg which is below Ga crustal abundance, while the median levels of Ge (2 mg/kg) are slightly higher from its corresponding crustal abundances. Levels of Co are negligible (median 2 mg/kg) and levels of In are below the method's detection limit. Measured elemental levels in mining wastes are much lower than expected according to the historical data (Berce, 1957 & Drovenik 1972).

Relatively high levels of Ag were measured (0.9 mg/g), especially from mining waste material which has higher Pb grades. Another element in association with Pb ore minerals is Sb although it reached relatively low levels with a median of 22 mg/g.

The highest grades of Pb and elements associated with its ore minerals are detected in mining waste deposits in front of the sub-horizontal concordant ore bodies (Sample 4 - Alma and Sample 3 - Gröll). This also seems to be the case for baryte as mining waste deposits marked as Sample 4 contain the highest measured levels of baryte (14 %). In the same two locations, the highest levels of Hg were also measured (100 mg/kg), which agrees with the historical data, which reported that most of the Hg in Litija was mined from concordant ore bodies. In general, Hg levels in Litija mining wastes are relatively high (median 65 mg/kg), which can have a significant negative impact on the local environment.



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FORECASTING AND ASSESSING EUROPE'S
STRATEGIC RAW MATERIALS NEEDS

Table 5: Results of the chemical analyses performed on bulk samples collected from the Litija mining waste deposits

Analyte	Unit	DL	Method	Sample 1	Sample 2	Sample 3	Sample 4	median
Al ₂ O ₃	%	0.01	FUS-OES	8.58	7.61	8.57	7.37	8.09
BaSO ₄	%	0.0002	FUS-OES	4.02	6.12	3.88	12.98	5.07
CaO	%	0.01	FUS-OES	0.58	0.02	0.03	0.02	0.03
Fe ₂ O ₃	%	0.01	FUS-OES	3.98	4.82	6.22	8.44	5.52
K ₂ O	%	0.01	FUS-OES	2	2.17	2.41	1.96	2.09
MgO	%	0.01	FUS-OES	0.4	0.21	0.28	0.23	0.26
MnO	%	0.001	FUS-OES	0.07	0.06	0.16	0.05	0.07
Na ₂ O	%	0.01	FUS-OES	0.38	0.09	0.17	0.10	0.14
P ₂ O ₅	%	0.01	FUS-OES	0.05	0.05	0.07	0.09	0.06
SiO ₂	%	0.01	FUS-OES	76.26	77.05	70.61	64.35	73.44
TiO ₂	%	0.001	FUS-OES	0.46	0.35	0.44	0.37	0.41
Ag	mg/g	0.5	FUS-MS	0.8	0.8	1.8	1	0.9
As	mg/g	5	FUS-MS	13	27	27	239	27
Be	mg/g	1	FUS-OES	2	1	2	2	2
Bi	mg/g	0.4	FUS-MS	< 0.4	< 0.4	< 0.4	< 0.4	-
Co	mg/g	1	FUS-MS	6	2	3	2	2.5
Cr	mg/g	20	FUS-MS	40	30	30	20	30
Cs	mg/g	0.5	FUS-MS	3.3	3	4.3	3.8	3.6
Cu	mg/g	10	FUS-MS	40	40	40	100	40
Ga	mg/g	1	FUS-MS	10	9	10	9	9.5
Ge	mg/g	1	FUS-MS	1	2	2	3	2
Hf	mg/g	0.2	FUS-MS	3.9	2.8	3	2.7	2.9
Hg	mg/g	5	CV-AA	11.8	29.8	99.9	100	64.9
In	mg/g	0.2	FUS-MS	< 0.2	< 0.2	< 0.2	< 0.2	-
Mo	mg/g	2	FUS-MS	< 2	< 2	< 2	< 2	-
Nb	mg/g	1	FUS-MS	7	5	6	5	6
Ni	mg/g	20	FUS-MS	< 20	< 20	< 20	< 20	-
Pb	mg/g	5	FUS-MS	1110	3310	12400	15500	7855
Rb	mg/g	2	FUS-MS	80	82	92	74	81
Sb	mg/g	0.5	FUS-MS	7.9	14.8	29	87.2	21.9
Sc	mg/g	1	FUS-OES	6	5	6	6	6
Sn	mg/g	1	FUS-MS	2	2	2	2	2
Sr	mg/g	2	FUS-OES	214	492	337	1084	415
Ta	mg/g	0.1	FUS-MS	0.5	0.3	0.5	< 0.1	0.5
Th	mg/g	0.1	FUS-MS	8.2	6.6	7	5.9	6.8
Tl	mg/g	0.1	FUS-MS	0.9	1.2	1.3	1.5	1.3
U	mg/g	0.1	FUS-MS	2.3	1.8	2.1	2.5	2.2
V	mg/g	5	FUS-OES	46	34	43	40	42
W	mg/g	1	FUS-MS	1	< 1	1	3	1
Zn	mg/g	30	FUS-MS	240	260	660	150	250
Zr	mg/g	2	FUS-OES	153	102	115	107	111
LREE	mg/g	0.1	FUS-MS	99.1	92.2	152.9	408.4	126.0
HREE	mg/g	0.1	FUS-MS	23.2	23.1	41.6	181.9	32.4



4.7 Evaluation of the Litija CRM potential

The reassessment of the volumes of mining waste deposits on an area of Litja baryte-Pb-Zn-Hg historical mine shows that 64,200 m³ of the total 99,200 m³ of deposited waste is still accessible. The remaining 35,000 m³ of material is occupied by residential buildings and therefore inaccessible.

The grades of ore elements and CRMs in the mining waste deposits are low. Median Pb grades in the mining waste deposits are 0.8%, while Zn grades are well below 0.1%. Although barite was mined after 1941, the median grade of baryte in mining wastes is only 5 %, while its maximum levels do not exceed 14 %. Low ore grades in the sampled material may be due to the sampling protocol, as samples were collected from the mining wastes surfaces where material (presumably lower grade ore) from the later period of mining was likely deposited, while older and possibly higher-grade mining wastes are buried below. For a more representative sampling of material at greater depths, a different and more advanced sampling approach needs to be used (e.g., drilling) as described in (Parviainen et al., 2020).

Despite indications that sphalerite in Litija contains elevated levels of CRMs such as Co, Ga, Ge, their levels in the bulk samples were relatively low and the potential for their extraction is insignificant. This may be related to the absence of Zn and its ore minerals in the analysed mining waste, most likely the consequence of the low amount of Zn ore minerals in the Litija ore bodies.

The possibility that the Litija mining wastes could be used as a potential source for CRM extraction is therefore minimal. Proper pre-processing of the mining waste material could increase the baryte grades, which have the greatest potential for extraction with a small-scale mobile and modular ore processing plant, but the feasibility of such an operation is also questionable with such low volumes and grades of material. Rail transport of the material to another location with an existing ore processing plant could also be a solution, but a feasibility study would need to be undertaken to assess the economic viability of such an operation.

The primary ore in the veins is not accessible at present in the Litija mine. As its exploitation would require large-scale exploration and investment, this ore has not been considered in the assessment. However, revisiting the primary ore deposits could increase the overall potential for CRM extraction. The entire Litija ore field area is poorly explored with modern exploration techniques (e.g., geophysics and diamond drilling) and is highly favourable for the discovery of new ore bodies or extensions to existing known ore bodies. Since reprocessing of mining waste material on the Litija area is unlikely to happen, they need to be remediated in the future. Their uncontrolled weathering and erosion may introduce significant amounts of potentially toxic elements (e.g., Hg and Pb) into urban soils, sediments, airborne particulate matter, and water bodies. The case study conducted can therefore raise citizens' awareness of historic environmental hazards in their local area, as well as assist local and state officials in making decisions for a healthier environment.



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