Innovative Processes in Mining and Quarrying in the Czech Republic (Innovative Processes of Extracting Raw Materials in the Czech Republic)

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Abstract. The first part of this article describes possible mining of lithium in the Czech Republic – brief geological conditions and mining methods, mining in Cínovec deposit in the past, and uses of lithium. This is related to another part of the article, which is focused on the foundation of a new field of study at VŠB-TU Ostrava, the first of this type in the Czech Republic. The field of study is focused on the preparation of graduates in the field of designing and realization of blasting works in surface and deep mining of mineral deposits, but also for opening and preparatory works. An inseparable part of the study is the professional experience leading to obtaining a blasting licence. The guarantor of this field of study is Milan Mikoláš. Next part of the article is dedicated to protection of conveyor belts, which is practised in Vršanská uhelná a.s., where there is currently about 19 kilometres of conveyor belt and its repair is very expensive and time-consuming. Vršanská uhelná a.s., after agreement with Matador, decided to try the ARB system (anti tear resistance breaker). The last part of the article presents Vršanská uhelná a.s., and their innovative way how to cooperate with the public through the project named Coal Safari, which provides excursions to mining sites for the public.

1. Lithium

1.1. General description of the element

The chemical element of lithium is silver-white, glossy, light, very soft and non-abrasive metal. They belong to the group of alkali metals together with sodium, potassium, rubidium, caesium and francium. Under normal circumstances, it crystallizes in the cubic crystallographic system, at a temperature below -200°C, there is a hexagonal allotropic modification. At a density of 534 kg.m⁻³, lithium is the lightest metal on Earth. The lithium pairs have a brown colour [3].

Like other alkali metals, lithium is an extremely reactive chemical element. It is volatile in the air, quickly covered with a layer of aggressive corrosive lithium hydroxide (LiOH), and subsequently a layer of lithium carbonate (Li₂CO₃); when ignited in the air, it burns while forming white lithium oxide (Li₂O) and lithium nitride (Li₃N). It burns with oxygen to form peroxide (Li₂O₂). With ozone in the atmosphere, it burns while forming explosive lithium ozonide (LiO₃).

It reacts with water to produce hydrogen: [3]

\[ 2\text{Li} + 2\text{H}_2\text{O} \rightarrow 2\text{LiOH} + \text{H}_2 \]

(1)
The reaction of lithium with mineral acids takes place exothermously to form lithium salt and hydrogen evolution:

\[
\begin{align*}
2\text{Li} + 2\text{HCl} & \rightarrow 2\text{LiCl} + \text{H}_2 \\
2\text{Li} + 3\text{H}_2\text{SO}_4 & \rightarrow 2\text{LiHSO}_4 + \text{SO}_2 + 2\text{H}_2\text{O} \\
3\text{Li} + 4\text{HNO}_3 & \rightarrow 3\text{LiNO}_3 + \text{NO} + 2\text{H}_2\text{O}
\end{align*}
\] (2)

With halogens, it combines directly at room temperature, only reacting with iodine after being heated to a temperature above 200°C. At higher temperatures it reacts with hydrogen to form lithium hydride (LiH), it forms acetylide (Li₂C₂) with carbon, and silicide’s (Li₆Si₂, Li₅Si, and Li₂Si) with silicon. With liquid ammonia, it reacts to form lithium amide LiNH₂, with gaseous ammonia, it forms lithium imide(Li₂NH) at a temperature of 400°C. With sulphur, it is combined to form lithium sulphide (Li₂S) at a temperature above 130°C, with selenium and tellurium reacting to form lithium selenide (Li₂Se) and lithium telluride(Li₂Te) already at temperatures considerably below the freezing point [3].

Lithium dissolves well in solutions of some organic substances, e.g. in ethylamine, it is not soluble in hydrocarbons. The solubility of lithium salts in water is the lowest of all alkali metals, with the exception of lithium chlorate LiClO₃ that on the contrary, is highly water-soluble; very poorly soluble lithium salts include lithium fluoride (LiF). An analytical evidence of lithium salts is the best carried out by the addition of hydrogen phosphate; in an alkaline medium, a white precipitate of almost insoluble lithium phosphate (Li₃PO₄) is formed [3].

![Figure 1. Cinovec - Czech Republic, Author: Lubor Ferenc](image)

1.2. The occurrence of lithium in nature

In nature, elemental lithium is not present as an element, it is found only in compounds in which it is exclusively monovalent. It is accompanied by sodium and potassium. The average lithium content in the Earth’s crust is 65 ppm. Natural lithium is a mixture of two stable 6Li and 7Li isotopes, another 5 lithium radioactive isotopes with nucleon numbers 5 to 11 were artificially prepared. [3]

The most important lithium minerals are eucryptit (LiAlSiO₄), spodumene (LiAlSi₂O₆), amblygonite ((Li,Na)Al(PO₄)(F,OH)), petalite (LiAlSi₃O₁₀) and lepidolite (K(Li,Al)₅(Si,Al)₄O₁₀(OH,F)₂). Other lithium minerals are relatively rare, e.g. triphyllin (LiFePO₄) and zinnwaldite (KLiFeAl₁₂(F,OH)₁₂AlSi₃O₁₀) [3]. The mineral with the largest lithium content (26.76% of Li) is griceite(LiF). Altogether, 131 minerals containing lithium were described [3].
1.3. Mining and supplies
The lithium deposits in lake sediments and brine in Chile and the USA are of the greatest importance for industrial mining. Most of the industrially available lithium reserves are found in Chile (9 Mt), Bolivia (9 Mt), USA (6.7 Mt), Argentina (6.5 Mt), China (5.1 Mt), and Australia (1.7 Mt). The annual mining of lithium minerals is around 40 kt. The world’s annual production of metal lithium reached 37 kt in 2015 [3].

Worldwide minable reserves are estimated at 34 Mt of pure metal. In Europe, the largest, not yet verified, lithium deposits are in Serbia - more than 1 Mt [1].

1.4. Lithium deposits and extraction in the Czech Republic
Significant lithium deposits are also available in the Czech Republic. The zinnwaldite veins in acid granites near Cínovec and Krupka (the registered Cínovec-south deposit) contain 140,000 tonnes of lithium. Dump heaps and slurry ponds, after former mining, contain other 5,000 tonnes of metal. The total deposits of ores with increased lithium, rubidium and caesium content were estimated to be at least 300 Mt with an average metal content of 0.117% of Li. Lithium mining already took place in Cínovec between 1953 and 1967. Further mining was abandoned due to high level of transport costs. The Cínovec Mine produced a total of 23 kt of Li concentrate. The production of elemental lithium took place from 1957 to 1968 at the LachemaKaznějov plant. According to the intentions of the German company SolarWorld, lithium mining was supposed to be restored in the Saxon side of the Cínovec deposit in 2016. The company Cínovecká deponie was granted permission to process the dump heaps. Deep mining on the Czech side of the Cínovec deposit is planned by the company Geomet [5].

![Figure 2. Map of mining areas, protected deposit areas and the Cínovec exclusive deposit, source: [6]](image-url)

Metasomatic pegmatites with zonal veins of lepidolite lithium mica, spodumene and petalite are located also in other sites in the Czech Republic, such as Verneřov near Aš, or Dobrá Voda near Velké Meziříčí; the surface vein of lithium pegmatite with the thickness of up to 13 m near Nová Ves near Krémže is also known; trilithionite samples from Rožné show the metal content of up to 3.3% of Li. The well-known mineral waters Vincentka (11.1 mg/l) and Ida also have significant
lithium contents. The brine of the Slaný coal mining area has an anomalously high content of lithium in the form of lithium bromide. The lithium content of this deposit is estimated to be 15,000 tonnes of metal, with 123,000 tonnes of bromine and at least 18 Mt of sodium chloride in the mine. Lithium deposits in the whole Czech Republic account for 1% of the world’s deposit. [1].

1.5. Mining by processing dump heaps
The company Cínovecká deponie, that is currently run by the people from the company RSJ, founded by Karel Janeček, and which has been granted a mining permit since last year, could carry it out. Its aim is to obtain lithium mica (and consequently lithium) from the waste of the old mining at the Cínovec and later, perhaps also in Krásno [9].

The Cínovec slurry pond was the property of the state owned company Diamo, which transferred it to another organization, apparently because of its non-profitability. The new owner’s acquisition was sand rather than lithium; in fact, the slurry pond is actually about ten meters thick white sand deposit. The then owner wanted to extract and sell it, but the lithium content made the original sand extraction plans more complicated. Pursuant to the Mining Act No. 44/1988 Coll., lithium is a reserved mineral and the mining company is therefore obliged to extract it as fully and economically as possible. Therefore, the intended sand quarry changed its owner and purpose [9].

The material contains roughly a quarter percent of lithium, which represents thousands of tonnes of pure metal. Obviously, it will not be possible to extract everything, but it is estimated that the minable amount is around 80 percent. For comparison, approximately 35,000 tonnes of lithium were sold on the global market in 2016 (i.e., recalculated to pure lithium, which is, however, not traded for purely practical reasons) [9].

Lithium would be extracted by open-cast mining in this area. An excavator would extract the sand, and the area would be reclaimed after mining. The lithium ore could then be magnetically separated because the local mineral containing it (zinnwaldite from Zinwaldt, the German name of Cínovec) also contains iron, therefore, it is magnetic, which is convenient coincidence for the mining company. Elsewhere in the world where lithium is extracted from other ores, it is not the case, and other methods are used. The ore would then have to be processed, but the exact procedure would depend on other circumstances [9].

1.6. Mining possibilities in Cínovec
Cínovec is a large, but, in terms of metal content, a relatively poor lithium deposit. Its disadvantage is the high cost of mining underground. On the contrary, positives are tin and tungsten deposits, the value of which reduces the production costs of lithium, a simple and safe process of ore processing, and an incomparably low environmental impact of mining activities on the environment and on the life of the population in the region. [2]

1.7. Mining method
The mineral can be extracted by the chambering method, while the use of blasting in the area of the old underground mine, where mining was already carried out in the past. For the most part, the mined material can be broken underground. Subsequently, the mine run is transported to the mouth of the galleries, [2].

The first minor processing of the material would occur there. The purpose will be to grind the material into smaller pieces and dilute it with water to create a mixture that will consequently be transported by a seven-kilometre pipeline “to the hill” where a complex with two more plants should be constructed, [2].

In the first plant, a mixture of ground material and water is passed through magnetic and gravitational separation. During this process, the tungsten and tin-based minerals are separated, and they are processed. Above all, however, lithium mica will be produced.
In the second treatment plant, which is also the most costly of all, a metallurgical process called sintering can be used, i.e. a combination of high temperatures and several chemical reactions creates the end product - lithium carbonate (Li$_2$CO$_3$), which is traded and also used, for example, in the above-mentioned batteries, [2].

1.8. Producing metal lithium

Lithium production can be performed by melt electrolysis of a eutectic mixture of 55% of LiCl and 45% of KCl. Electrolytic lithium production takes place in open electrolysers at 420°C, with a voltage of 6.5 V, current density reaches the value of 20 A. The iron cathode separates almost pure lithium with a small amount of potassium [3].

To a limited extent, metallothermic lithium production can be carried out by reduction of lithium oxide with silicon or reduction of lithium fluoride with aluminium. Metallothermic production takes place at temperatures of about 1000°C in the presence of calcium oxide as a slag-forming additive: [3]

\[
2\text{Li}_2\text{O} + \text{Si} + \text{CaO} \rightarrow 4\text{Li} + \text{CaSiO}_3
\]

\[
6\text{LiF} + 2\text{Al} + 4\text{CaO} \rightarrow 6\text{Li} + \text{Ca(AlO}_2)_2 + 3\text{CaF}_2
\]

1.9. Processing of ore concentrate

The main raw material for the preparation of lithium chloride needed for electrolysis is the mineralspodumen (LiAlSi$_2$O$_6$) which can be processed by a number of processes. Acidic processes are common, for example a sulphating process where the ore concentrate is leached in concentrated sulphuric acid at a temperature of 1050-1100°C. The lithium is passed into the solution as lithium sulphate (Li$_2$SO$_4$), due to the action of K$_2$CO$_3$, precipitating from the solution as a poorly soluble Li$_2$CO$_3$, which is converted to lithium chloride (LiCl) by being dissolved in hydrochloric acid. The chlorine process is based on the action of chlorine gas on the concentrate at 940°C, the product being lithium chloride directly. The low-temperature chloride process uses decomposition with hydrochloric acid at 100°C [3].

Alternate melting processes were developed for the processing of zinnwaldite; the sulphate one uses melting the concentrate with K$_2$SO$_4$ at 850°C. The gypsum process utilizes the melting of the concentrate with a mixture of CaSO$_4$ and Ca (OH)$_2$ at a temperature of 950°C. The limestone process uses CaCO$_3$ for decomposition at 820°C [3].

In addition to the melting processes, autoclave processes are used, where NaOH, Na$_2$SO$_4$, or Na$_2$CO$_3$ is used to decompose the ore concentrate. Autoclave decomposition takes place under elevated pressure at 250-300°C [3].

1.10. Use of lithium and its compounds

Large amounts of lithium (24% of total consumption) are consumed in the form of lithium carbonate (Li$_2$CO$_3$) in the ceramic and glass industry to reduce the melting point, viscosity adjustment and thermal expansion coefficients – glass-ceramic hob. Lithium carbonate and lithium oxide (Li$_2$O) represent an important component of transparent glazes for reduction firing of ceramics. The use of lithium carbonate to reduce the melt temperature in electrolytic aluminium production is significant as well. The lithium bromide solution is used as a replacement for chlorofluorocarbons in refrigeration equipment. Lithium stearate is used to adjust the viscosity of lubricants and oils - lithium soaps. Other 13% of the world’s consumption is represented by lithium-based catalysts for the production of rubber, plastics and pharmaceuticals, and 39% of the total lithium consumption in the form of lithium-iron phosphate (LiFePO$_4$) is used for the production of anodes in Li-Ion cells [3].
Lithium hydride (LiH) is the starting material for the preparation of hydrides Li[AlH₄] and Li[BH₄], which are important reducing agents in organic chemistry, and they are verified as experimental sources of hydrogen for the use as fuel in automobiles. Phenyl lithium (C₆H₅Li) is a reagent for the preparation of olefins from aldehydes and ketones (Wittig reaction). Lithium nitrate (LiNO₃) and lithium chlorate (LiClO₃) are used in pyrotechnics – they give the flame an intensely crimson colour. Lithium silicate (Li₂SiO₃) is the basic ingredient of concrete curing agents. Crystalline lithium fluoride (LiF) perfectly transmits UV radiation, and it is used for the construction of laboratory and measuring instruments working in the UV spectrum. Lithium iodide (LiI) serves as a neutron detector and as a luminophor of halide lamps. Lithium molybdate (Li₂MoO₄) is a corrosion inhibitor. Lithium titanate (Li₂TiO₃) is used to prepare white glazes and enamels. Wolfram lithium (Li₂WO₄) is used to prepare dense flushing solutions for oil wells. Lithium tantalate (LiTaO₃) and lithium niobate (LiNbO₃) have piezoelectric properties, and they are used in the production of motion detectors. The lithium cyanide (LiCN) serves as a laboratory reagent. [3]

Lithium played an important role in the development and production of thermonuclear weapons. Using nuclear reactions, hydrogen isotope 3H-tritium is prepared from lithium, which is the fuel for thermonuclear fusion. Lithium deuteride (LiD) also serves in a thermonuclear bomb as a stable carrier and a deuterium reservoir - the second substance necessary to carry out the thermonuclear reaction. The first usable hydrogen bomb (it fitted inside an airplane), the Soviet RDS-6s by the academician Sacharov, was made in 1952 using lithium and its hydride. [3]

2. Vršanská uhelná, a.s.

The stock company Vršanská uhelná a.s. ensures lignite mining in the Vršany area in the central part of the North Bohemian Brown Coal Basin. It has coal reserves with the longest lifetime in the Czech Republic within the existing territorial limits. In 2013, the company concluded a contract for the supply of coal to the Počerady power plant with the ČEZ power company up to the time of the quarry decoaling, i.e. with the possibility of more than 50 years of life. For the company Vršanská uhelná a.s., this contract means a long-term perspective, for the North Bohemian region it is a prerequisite for guaranteeing stability in the area of development and employment. [10]

Vršanská uhelná is a member of the coal mining and energy group together with Severnienergetická a.s., the power plant Sev. en EC in Chvaletice in the Pardubice area and a number of other service companies. Lignite mining takes place at the ČSA Quarry and at the Vršany Quarry. [10]. The Vršany Quarry is the youngest lignite quarry located in the central part of the North Bohemian Brown Coal Basin. It has lignite reserves with the longest life in the Czech Republic within the existing territorial limits up to the 2055 horizon. Mining at the Vršany quarry takes place at a site 7 km long and 4.5 km wide with an area of 30 km². The thickness of the coal is 25-35 meters and its age ranges between 20 and 25 million years. The coal has a higher ash content (about 30%) and a lower calorific value (11 MJ.kh⁻¹), and is therefore mainly used as coal for power plants. [10]

The KU800 wheel excavator, which mines the top and middle sections of the overlying formation, the ZP6600 type stacker and the 1800 mm wide belt conveyor are used to extract the overburden. [10]
Figure 3. KU800 wheel excavator

The actual achieved hourly performance in the limited ČSA Quarry conditions is up to 2500 m³/hour. The KU300 wheel excavator with 13 buckets with the capacity of 365 litres and the yield of up to 1200 m³/hour. [10]

| Table 1. Technical data of wheel excavators produced by the company UNEX, source: [8] |
|---------------------------------------------------------------|
| **Type**           | KU 300 | KU 800 |
| Theoretical performance (m³/h) | 1 800   | 5 800   |
| Specific breaking force (kN/m) | 180     | 145     |
| Height range (m) | 19.6   | 32     |
| Weight (t)       | 1 240  | 4 500  |
| Wheel diameter (m) | 7.6  | 13     |
| Travel speed (m/min) | 6 | 3     |

3. ARB system (Antifear Resistance Breaker)  
It is a unique novelty that was started to be used by the Vršanská uhelná rubber industry workers in cooperation with Matador conveyor belt manufacturer. It is a system of steel cables placed one meter across the zone. If a crack appears, such a cable system should ensure that the crack does not continue to expand and prevents further damage to the belt. The system completely stops the object that caused the crack or changes its direction while shutting down the conveyor line [4]. The ARB system is not a complete novelty; different types of similar systems are used in the world, such as in Slovakia, however, in the North of Bohemia, this technology is unique [4]. In Vršanská uhelná, a.s, about 19 km...
of steel-string zone is in operation. Its properties, including high resistance, are ensured by a set of steel ropes - up to 118 pieces for less than 2 meters of the belt width. Moreover, the steel strings are treated to better adhere to the rubber into which they are planted [4]. Vršanská uhelná, a.s. however, it is not innovative only in terms of innovative technologies used in mining, but also in its approach to the environment and society. Vršanská uhelná organizes many public educational events, contributes to schools and carries out reclamation [4].

![KU300 wheel excavator](image)

Figure 4. KU300 wheel excavator [8]

4. Coal Safari
Vršanská uhelná, a.s and Northern Energy, a.s. has been organizing excursions directly to the quarries in full operation, and to the reclamation areas under the name of Coal Safari since 2009. Thus, it makes it possible for the public to get acquainted with the technology of lignite mining, as well as with the subsequent restoration of the landscape after mining. Over the course of the project, 23,000 people from all over the Czech Republic, as well as from abroad, have become acquainted with this activity. [7].

The participants of the Coal Safari have a choice between three different routes.

4.1. Route 1: ČSA Quarry
This route includes a visit to the Most Hippodrome, the interior sightseeing terrace of the ČSA Quarry, the KU800 and KU300 excavators, the ZP 6600 stacker for overlying rock, and the reclamation in the area of the dean church and future Most Lake, [7].
Figure 5. Coal Safari Route 1 [7]

Legend: skrývka - overburden, uhlí - coal, lom - quarry, zakládání - backfill, START budova - START building, lom Vršany - Vršany Quarry, jezero Most - Most Lake, hipodrom – hippodrome

4.2. Route 2: Vršany Quarry
On this route you can see the Most Hippodrome, the landfill machine, the viewing terrace of the Vršany Quarry, the overburden mining using the KU800 and KU300 excavators, or possibly a demonstration of Most Lake, which is being created [7].

Figure 6. Coal Safari Route 2 [7]   Legend: vyhlídka – Viewpoint
4.3. Route 3: Reclamation Route

This route is intended for larger groups with their own transport. The excursion organizer only provides a guide. [7]

The route runs through the Benedict Complex, the Most Hippodrome, the observation terrace of the Vršany Quarry, the waterworks of Vrbenský (Matylda), the dean’s church complex, future Lake Most [7].

Figure 7. Coal Safari Route 3 [7]

Legend: přesunutý kostel - relocated church

5. Conclusion

The aim of the article was to present the solution applying innovative ways of extracting minerals, but also the utilization of mining areas to inform the general public about the use of minerals and innovative technologies.

After discussing the general innovation methods, the article dealt with the specific ways of extracting lithium and lignite in the Czech Republic.

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