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Knjižnice - Arhivi - Muzeji

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Abstract

During the Middle Ages, miners in Central Europe suffered from contact with many toxic minerals. Those known at that time were minerals of mercury, lead, and arsenic. There was also suspicion in the silver mining district of Joachimsthal that a certain black mineral present was causing unexplained sickness among miners. It was only at the beginning of the twentieth century that the mystery was revealed when the phenomenon of radioactivity was explained. It is also interesting to mention that one of the components of the toxic radioactive minerals was used under controlled conditions as a cure for certain disease. For many centuries miners’ disease was either attributed to the presence of goblins and ghosts in mines, or to the belief that some ores were bewitched. This changed when chemical analysis proved the existence of arsenic in these ores. In modern times the artisanal gold recovery using mercury by the so-called garimpos in Latin America is a major pollution and health hazard problem. The role played by medical doctors of this period, e.g., Agricola, Paracelsus, Geoffroy, Scopoli, and others are outlined.

Introduction

It may look rather surprising that the first comprehensive books on mining and metallurgy were written by a medical doctor. It was Georgius Agricola (1494-1555) (Figure 1) the medical doctor in Chemnitz who was treating sick miners in the region and got interested in mining and metallurgy. He visited mines and smelters, asked questions, took notes, and then compiled this information in a number of books in Latin, the language of the scholars at that time, that became the basis of mining and metallurgical literature for about two centuries (Table 1). A characteristic of Agricola’s books was the large number of woodcuts illustrating the text. Figure 2 shows an illustration from his book De Re Metallica describing the production of mercury. Intense fumes emitted at the workplace can be seen.
Table 1 - Mining, geological, and metallurgical books by the medical doctor Georgius Agricola

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<tr>
<th>Year published</th>
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<td>Bermannus</td>
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<td>De Veteribus et Novis Metallis</td>
<td>Historical and geographical references to the occurrence of metals and mines, and history of mines in Central Europe</td>
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<tr>
<td>1546</td>
<td>Return Metallicarum interpretatio</td>
<td>A collection of about 500 Latin terms in mineralogy and metallurgy with their German equivalent</td>
</tr>
<tr>
<td>1546</td>
<td>De Orlu et Causis Subterraneorum</td>
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<tr>
<td>1546</td>
<td>De Natura eorum quaee Effluunt ex Terra</td>
<td>A short account on substances which flow from the earth, e.g., water, gases, and bitumen</td>
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<tr>
<td>1549</td>
<td>De Animantibus Subterraneis</td>
<td>A short work on animals who spent a portion of their life underground (serpents, lizards, etc.)</td>
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<td>1550</td>
<td>De Precio Metallorum et Monetis</td>
<td>Description of minting, comparison of different coins and their values</td>
</tr>
<tr>
<td>1556</td>
<td>De Re Metallica*</td>
<td>A treatise on prospecting, mining, assaying, beneficiation, smelting, and other topics</td>
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* Went through numerous editions in the sixteenth and seventeenth centuries and translated in German and Italian. First English translation was made in 1912 by the mining engineer Herbert C. Hoover (who became president of the United States 1929-1933) and his wife the geologist Lou H. Hoover.

The Bad-luck Mineral

It happened that the miners in the town of Joachimsthal suffered during the sixteenth century from a mysterious and untreatable sickness that was known to the physicians of that time as the "miner's sickness". The German miners who were exploiting the rich silver deposits there often came across a heavy lustrous black mineral which was for them bad luck because it did not contain silver. Also, because it was as black as pitch, they called it "Pechblende" since in German "Pech" stands for pitch or for bad luck. It became known in English as "pitchblende". Soon, the miners' sickness was attributed to this black mineral.

Joachimsthal is located on the southern slopes of the Erzgebirge1 mountains at an altitude of 650 m, in an area exceptionally rich in ore deposits. The town was founded by Count Stephan Schlick in 1516 when few years earlier silver was discovered. The town was named after its patron Saint Joachim, Mary's father. The name was chosen to harmonize with the then existing settlements in Saxony on the other side of the mountains known as Annaberg (1491) and Marienberg both from Jesus' family. Further settlements in the neighborhood, Freiberg (1168) and Schneeberg (1446) are also known by their silver discoveries.

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1Joachimsthal (Joachim's Valley) is Jachymov in Czech and the Erzgebirge (Ore Mountains) is Krušné Hory. The German names are used here in the text when the Kingdom of the Lands of Czech consisting of Bohemia, Moravia, and Silesia were part of the Austrian Empire.
The town recognized remarkable prosperity, silver production amounted to about 14 tonnes per year, the population increased gradually, becoming the second largest town in Bohemia after Prague, with a population mostly German miners. The word "dollar" is derived from the silver "Thaler" in reference to Joachimsthal. However, during the religious war of 1546-1547 silver production decreased to 1.5 tonnes and the lack of pumps needed for deeper mining made it difficult to compete with silver from the new Spanish American colonies, which was arriving in increasing quantities on the European market. The town knew its depression and the population decreased drastically.

Agricola practiced medicine in Joachimsthal from 1527 to 1531 and wrote his book "Bermannus" there. It is known also that he met there a native artist of the town, and engaged him to make the illustrations for his new book De Re Metallica which was published one year after his death. He also stayed a month there in 1550 to examine the ailing Count Hieronymus Schlick, brother of Stephan Schlick. Figure 3 shows a doctor and a nurse attending to a sick miner in the town's hospital; from the window one can see mining activity. Figure 4 shows the town's apothecary from a woodcut dated 1568.

A discovery by Klaproth

Joachimsthal was about to become a ghost town when Martin Klaproth (1743-1817) a pharmacist in Berlin, who became later professor of chemistry at the Royal Mining Academy in Berlin, discovered that the black mineral from Joachimsthal can be used to give glass a brilliant yellow color with green fluorescence when added to the molten batch. He was also convinced that this mineral must have contained a new metal. This discovery coincided with the discovery in 1781 of a new planet in the solar system by his compatriot William Herschel who had immigrated to England in 1757 and called the planet Uranus. Hence Klaproth named the new metal "uranium" to honor his compatriot.

In 1815 the Austrian chemist, Adolf Patera at the Imperial Geological Institution in Vienna investigated the possibility of the commercial application of Klaproth's discovery. He devised a procedure for preparing "uranium yellow" known at that time as "Uranoxyd-natron" which is the "yellow cake" or sodium uranate. Consequently, a plant was built in 1854 next to the silver smelting operations to process this black uranium mineral for pigment manufacture which was kept a guarded secret and a monopoly of Bohemian glass manufacturers. Few years later, however, the silver operation became unprofitable and the government of the then existing Austrian Empire decided to close all the mines at the end of the nineteenth century. In 1873, the town suffered further from a great destructive fire.
The discovery of radioactivity

Joachimsthal was about to become a ghost town again when new discoveries came to its rescue. One year after the discovery of X-rays by Wilhem Konrad Roentgen in 1895 in Germany, came the discovery of radioactivity by Antoine Henri Becquerel in 1896 in France when he was trying to find a relation between phosphorescence of uranium salts and the possibility of emission of X-rays. Indeed, he found that pure uranyl potassium sulfate crystals did fog photographic plates although they were wrapped in black paper. This was followed by the search of Marie and Pierre Curie for the hypothetical element causing the intense radioactivity of the mineral containing uranium. The Austrian government permitted that 100 kg of the waste material from the Joachimsthal uranium-based pigment factory to be dispatched to Paris for the Curies. Marie Curie succeeded in the isolation of polonium in 1898 followed by radium in December of the same year.

Curie therapy

As soon as the Curies announced that radium salts emit light in the dark (Figure 5), two distinguished physicists at McGill University in Montreal, Ernest Rutherford and Frederick Soddy immediately took up investigation of this new element. Within few years the area was thoroughly explored and important conclusions regarding the origin of radium and polonium, the radioactive decay, the structure of the atom, isotopes, etc., were formulated. The discovery in 1903 that radium emitted gamma rays was put into practice for treatment of cancer by the so-called «Curie Therapy», hence the production of radium became in great demand. A small plant was erected east of Paris to treat on a nonprofit basis the Joachimsthal residue shipped from Bohemia, for its recovery.

When the Curies together with Becquerel were awarded the Nobel prize in 1903, the attention was drawn to Joachimsthal. In the same year, the Austrian Government declared an embargo on the export of ore and residue and asked Carl Auer von Welsbach the famous Austrian chemist specialized in the recovery of rare earths to devise a method for radium recovery. At the same time the Austrian Academy of Sciences founded an Institute for Radium Research, the first such organization in Europe, with the physicist Stefan Mayer as its director. As a result of the boycott, exploration for radium was launched world wide. Ores were discovered, plants were erected, and small amounts of radium were produced at a very high cost - $100,000/gram.

In 1905, Stefan Meyer proved that the Joachimsthal mine waters indicated high content of radium. In 1906, the first radium spa in the world was opened there which attracted a large number of wealthy...
tourists. A year later, a radium separation unit was installed in the same building that was used for preparing uranium yellow pigment. It became the leading radium producer in the world.

During the heydays of Joachimsthal, radium was the magic word, for example, the radium beer in the pubs, the radium soap, etc. However, the death of the American Senator M. Byers changed all that. The senator, who was suffering from certain disease, was recommended to him to drink radioactive water from a special kit available on the market composed of a small reservoir containing a radium salt in water. After one month drinking this water, however, he died. Autopsy showed that his bones were very high in radium. Immediately the US Government ordered the removal of all products containing radium from the market.

In September 1910 the International Radiology Congress was held in Brussels in Belgium under the sponsorship of the Belgian industrialist Ernest Solvay (1838-1922) in which leading scientists in the field of radioactivity (Figure 6) considered for the first time the question of preparing standard samples of radium for comparison of measurements carried out at different laboratories.

Paracelsus

Theophrastus Bombast von Hohenheim Paracelsus (1493-1541) (Figure 7), a medical doctor from the University of Basel in Switzerland, spent most of his life wandering in Europe. He worked in a Cornwall mine, inspected the copper mines in Sweden, spent a year working in Idria mercury mine, and worked in the silver mines in Schwatz in the Austrian Tyrol. The Inn valley in the Tyrol was then a metallurgical center where primitive techniques made mining and metal working extremely hazardous. Affections of the lungs gave Paracelsus an opportunity to help patients and to study disease. The fruit of this work was the first book ever written on an occupational disease: Von der Bergsucht und anderen Bergkrankheiten (The Mountain Passion and other Mining Sickness) published in 1527.

Superstitious contemporaries assumed that miners' diseases were inflicted by the mountain spirits who guarded veins of ore.
and punished transgressors. Miners paid with their health for digging into the earth and robbing her treasures. Paracelsus dismissed all this. He attributed miners’ diseases to poisoning by metal vapors, that is, respiratory afflictions, and treated them as such. This is correct as a general approach, but his details were confused and little can be made of them in modern terms. Among other errors, Paracelsus took it for granted that his discoveries in metabolism applied to everything. Nevertheless, his book contained numerous correct observations, broke ground in the field of chemical substances that can be used to cure patients, and ignored the goblins. He authored a number of books but these were medical not metallurgical. They were all published after he died at the young age of 48.

Paracelsian contributions included the use of laudanum (opium) in medical treatments, the first clear description of metallic zinc, the first descriptions of the preparation of hydrochloric acid, tin tetrachloride, and ammonium sulfate. He deflected the activities of chemists from the pursuit of the transmutation of metals and the elixir of life into the preparation of drugs and medicines for treating human disease.

Ramazzini

Bernardino Ramazzini (1633-1714) (Figure 8) Italian physician noted the harmful effect of metals especially mercury, described lead poisoning in painters and potters, the diseases of those who handled antimony, and silicosis in stone mason’s. He was born in Capri, studied in Parma and Rome, appointed professor of medicine in Modena 1682-1700, then in Padua 1700-1714. Authored: De morbis artificium diatriba in 1700 (Figure 9) in which he systematically described the relationship between metals and symptoms of metal poisoning in metal workers

Geoffroy The Elder

Both Pliny the Elder (23-79AD) and Pedanius Dioscorides (50AD?) were familiar with arsenic sulfides: orpiment and realgar, know as sandarac. The metalloid arsenic was isolated by Albertus Magnus (1193-1280). According to a Chinese encyclopedia published about 1600, the poisonous properties were thoroughly described. The French physician Etienne François Geoffroy (1672-1731) (Figure 10) known as Geoffroy the Elder wrote about the poisonous nature of arsenic and its damage to the hands and feet of miners. Geoffroy was professor of chemistry at the Jardin du Roi in Paris and physician to the
King of France. He compiled the first table of affinities of chemical reactions in 1718 and wrote a three-volume work in Latin on Materia Medica which was published in 1741 after his death. French translation appeared in Paris in 1743 in seven volumes, and in German in Leipzig in 6 volumes between 1760 and 1766.

**Kobolds in Mines**

Near the end of the fifteenth century, a troublesome and supposedly worthless mineral was found in a large quantity in the mines on the borders of Saxoy and Bohemia. The miners disliked it because of the labor of removing it and also because of the arsenic it contained injured their health. They called it Kobold, i.e., goblin or a ghost that is responsible for their suffering. The Kobolds, according to an ancient German superstition, delighted in destroying the work of the miners, causing them endless trouble. In mining towns the people used to pray in the churches for deliverance from the power of these malicious spirits.

**Cobalt**

About the middle of the sixteenth century a blue color for pottery and glass was prepared from this mineral. An industry was developed in Saxony based on the blue glass manufacture which became very popular. It was from this mineral that the Swedish chemist Georg Brandt (1694-1768) discovered in 1730 a new metal that he called cobalt. The ore resembled a copper ore in some of its properties but did not yield copper. This testified to the belief of German miners of the day that the false ore was bewitched. An analysis of the mineral done in 1810 by Wilhelm von Hisinger revealed it to be a cobalt sulfide. The mineral is now known as linnaeite, in honor of the Swedish naturalist Linnaeus.

Brandt was born in Riddarhytta, Vestmanland, where his father operated a copper smelter, an iron works, and some mines. He sent his son to study medicine and chemistry at Leyden in the Netherlands under Herman Boerhaave. Before his return home in 1727 George Brandt stopped in the Harz where he visited some metallurgical plants. He was then put in charge of the chemical laboratory at the Bureau of Mines in Stockholm. He moved later to the Royal Mint and in 1730 became its assay master.

**Nickel**

Axel Fredrik Cronstedt (1722-1765) faced a situation similar to that of his teacher Brandt when he examined another ore that resembled copper ore but did not yield copper. The miners named this ore Kupfernickel, i.e., Old Nick's copper in reference to the devil. On the other hand, this false copper ore was not a cobalt ore either and did not impart a blue color to glass as cobalt ore did. In 1751, Cronstedt obtained green crystals from this ore which when heated with charcoal yielded a metal that certainly was not copper. It resembled iron and cobalt, though it was different from both. He noted that the metal was attracted by a magnet - the first time anything but iron had been found subject to magnetic attraction since the days of Greek philosophers. In 1754 Cronstedt named the new metal nickel. The mineral from which the metal was first extracted is now called nicolite or nickeline, a nickel arsenide, NiAs.
Cronstedt was born on December 23, 1722 in Stroepsta, Södermanland in Sweden as the son of a high ranking army officer. He was trained in mathematics and the physical sciences, then studied mining and mineralogy under Brandt and was appointed as metallurgist in the Swedish Bureau of Mines in Stockholm. Cronstedt reformed mineralogy by initiating a classification of minerals not only according to their appearance, but also according to their chemical composition. In 1758, he published this new system in a book entitled in translation "Essay on Mineralogy or a Classification of Minerals".

Cronstedt introduced the blowpipe into the study of minerals. By directing a thin jet of air into a flame, it increased the heat of the flame. When this hot flame impinged on minerals, much information could be learned from the color of the flame, the vapors formed, the color and nature of the oxides or metallic substances formed out of the mineral, and so on. For a century the blowpipe remained the most useful instrument in a metallurgical laboratory, but its use called for a great skill. It was rendered obsolete by the invention of spectral analysis in 1857. Cronstedt died in Stockholm on August 19, 1765 at the young age of 43. The mineral cronstedite was named in his honor. He was a member of the Swedish Academy of Science and was bestowed the title of baron.

Amalgamation and the Environment

Mercury was known to the ancient Greeks and mercury mines in Almadén in Spain were extensively worked by the Romans who knew of its poisonous nature. Although the Romans were acquainted with the fact that mercury dissolves gold and silver, it does not appear that they applied this knowledge to the extraction of gold and silver from their ores. Vanoccio Biringuccio mentioned the amalgamation of ores in his book, *De la Pirotechnia*, published in 1540 while Georgius Agricola wrote that mercury fumes loosen the teeth.

New Spain

It was Bartholomeo de Medina who applied the amalgamation process in Pachuca in Mexico on a large scale in 1566. The ores treated by this process contained, beside metallic silver, the sulfide, the chloride and other compounds of silver. At that time, Mexico was devoid of running water, and therefore water-power cannot be obtained to crush and grind the ore. This was, however, effected by grinding mills worked by horse or mule power, and termed arrastra. It is a circular, shallow, flat-bottomed pit, 3 to 6 meters in diameter, paved with 30-cm thick hard stones, e.g., granite, basalt, or compacted quartz.

In the centre, a vertical shaft, carrying four horizontal arms, to each of which is attached a heavy stone by chains. These grinding stones weigh from 200 to 400 kg each, their forward ends being about 5 cm above the floor; their other ends drag on it. They are moved by mules walking round outside the arrastra, the speed varying from four to eighteen turns per minute. An arrastra of 3 meters in diameter rakes a charge of about 225 kg of ore, and treats about 1 ton in 24 hours. The wear sustained by the grinding is about 10% of the ore crushed. The mules are generally blindfolded and tied together (Figure 11); one mule for every three tons.

*Figure 11. Amalgamation of silver ores in arrastras.*
The crushed ore in the form of mud is then transferred to the amalgamation yard, called "patio", allowed to dry if necessary, then made into "tortas" or flat circular heaps about 30 to 50 cm in thickness, and containing about 100 tons of ore (dry weight). On the first day, about 5-6% of common salt is spread over the surface and incorporated with the mud by driving six to twelve mules over every part of the heap. On the second day, about 3 to 4 kg of "mag-istral", which is an impure mixture of copper and ferrous sulfates, is added and well trodden in by mules as above. Immediately after, 6 to 8 kg of mercury for each kg of silver in the ore is added, by squeezing it through a canvas bag and scattering it in fine globules over the entire torta. The mud is again trodden to incorporate the mercury. Samples are taken daily from every part of the heap, and tested by panning; the appearance of the amalgam indicates the extent to which the amalgamation has taken place, and whether the magistral is deficient or in excess, so that correction can be made if necessary.

The heap is trodden by mules every day until the amalgamation is complete, which may require 2 to 4 weeks. On the last day, a fresh quantity of mercury equal to about four times the weight of silver present, is added to render the dry amalgam fluid and to assist in its collection. The material of the heap is then washed in large tubs filled with water to remove the fine ore particles, leaving behind the amalgam. The amalgam usually contains 20% silver. After straining through canvas and squeezing, it is made into small balls or flat cakes, and charged in iron retorts to distill off the mercury. The silver which is left behind, termed patio pina, is then cast into bars in the usual way.

The recovery of silver by this process was about 75%, but dropped to below 60% when the ores contained an appreciable amount of base metal sulfides, particularly those of zinc, arsenic, and antimony. When the ore contained gold, some mercury was added in the arrastra to recover the gold first, and the silver was subsequently obtained by means of the Patio Process. This was applied successfully to the auriferous silver ores of Zacatecas. This process has been in operation till the 1920s, when tube mills and the cyanide process were introduced.

**Austrian Empire**

The Austrian Empire possessed one of the largest mercury mines in the world located in Idria. Two stamps were issued in 1990 by the former Republic of Yugoslavia to commemorate 500 years of the exploitation of the mine (Figure 12). Schemnitz was an important metallurgical center. It was there that one of the first European School of Mines was founded in 1762 by Empress Maria Theresa. In 1764, the Empress sent her two sons Prince Josef and Prince Leopold to visit this mining district to get first hand information about mining and metallurgical operations. Prince

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1. The chemical reactions which take place in this process are probably the following:

\[ 2Fe^{2+} + Ag_2S \rightarrow 2Fe^{2+} + 2Ag^+ + S \]
\[ 2Cu^{2+} + Ag_2S \rightarrow 2Cu^{+} + 2Ag^+ + S \]

Silver ion will be complexed by the sodium chloride, but the solution will be decomposed by mercury to form metallic silver and mercurous chloride:

\[ 2AgCl + 2Hg \rightarrow 2Ag^+ + Hg_2Cl_2 + H_2 \]

Silver is then dissolved in the mercury, forming amalgam. All the mercury which is thus converted into mercurous chloride is lost, and it amounts to about double the weight of the silver obtained. Some silver sulfide may also be reduced directly to metallic silver by the mercury:

\[ Ag_2S + Hg \rightarrow HgS + 2Ag \]

2. From 1493 to 1575 the mine belonged to the Republic of Venice, from 1575 to 1918 to the Austrian Empire, and from 1918 to 1943 under Italian administration. After World War II it was administered by Yugoslavia. After the fall of the communist regime in 1991 the mine belonged to the newly independent Republic of Slovenia. It is planned to close the mine in 2005.

3. Now Banská Štiavnica in Slovakia. Not to be confused with Chemnitz where Agricola served as Burgermeister, and was named Karl Marx Stadt during the communist regime of the German Democratic Republic.
Josef was crowned as Roman King in Frankfurt on April 3, 1764 and became known later (1780-1790) as Josef II, Austrian Emperor and King of Hungary. Prince Leopold became Emperor of the Austrian Empire from 1790 to 1792.

Scopoli

The medical doctor Giovanni Antonio Scopoli (1723-1788) (Figure 13) studied the health of miners working in the Idria mine. He was born in Tyrol and obtained a medical degree from the University of Innsbruck. He worked as the physician of the mercury mines of the Treasury of the Austrian Empire at Idria in Krain (1754-1769). He investigated thoroughly the hygiene and diseases of the miners, lectured on mineralogy and chemistry. He was appointed Professor at the Schemnitz Mining Academy in 1769 to replace Jacquin who had moved to Vienna. In the last period of his life Scopoli was appointed Professor of Chemistry and Botany at the University of Pavia, Italy. His scientific heritage comprises more than thirty major studies published in Latin, German, and Italian. He published a book on the symptoms of mercury poisoning among miners, others on mineralogy and crystallography, chemistry, and metallurgy:
- De Hydroargyro Idriensi Tentamina, 1761
- Mineralogische Vorlesungen, 1771
- Principia mineralogiae systematica et practicae, 1772 (in Italian 1778, in German 1786)
- Crystallographia Hungarica, 1776
- Fundamenta chemiae, 1777 (in Italian 1780, in German 1786)
- Anfangsgründe der Metallurgie, 1789.

Born

In 1771 Ignaz Edler von Born (1742-1791) (Figure 14) was appointed assessor of the Mint and Mining Court Chamber in Prague. Born organized scientific and cultural activities, first in Prague and then in Vienna, where he moved in 1776 to take up a post in the Natural History Cabinet. A year later he became again directly concerned with mining and metallurgy by joining the Mint and Mining Court Chamber. In 1786 he published in Vienna a treatise on amalgamation entitled Über das Anquicken der gold- und silberhaltige Erze, Rohsteine, Schwarzlufer, und Hüttenspeise* (Figure 15). There were reasons why Emperor Joseph II decided that Born's amalgamation method should be made public although there was a ban in the empire to publish books on mining. He had hopes for an increased trade in mercury with countries which would take up amalgamation. He also accepted that secrecy over the process could not be maintained for long because, sooner or later, accounts of its working would be transmitted abroad.

* Amalgamation of Gold and Silver - Containing Ores, Raw Rocks, Black Copper, and Smelter Speiss
Born's book on amalgamation was translated in French in the following year and published in Bern under the title *Méthode d'extraiter les métaux par le mercure. Another French edition appeared in 1788 in Vienna under the title Méthode d'extraiter les métaux par l'Amalgame des Mineraux. Méthode d'extraiter par le mercure. An English translation was published in 1791 in London by the Chemical Society and entitled *Baron Inigo Born's new Process of Amalgamation of Gold and Silver Ores and Other Metallic Mixtures.*

In September 1786 he organized an International Conference on the processing of silver ores. The Conference was held at Skleny near Schmtnitz in the Austrian Empire. This conference was the first of its kind; it attracted 24 experts. However, the conference should not be compared to todays conferences. It was not held on fixed days with speakers organized in sessions, but rather it was held during few months and the participants did not all arrive and leave at the same time. The purpose of the Conference was to demonstrate and discuss a new process developed by Born for treating sulfide ores containing silver. During the conference it was agreed to form an international "Society for Mining Science" (Die Societät der Bergbaukunde). Many engaged in the mining industry worked on their own and did not share knowledge. Born believed that this hindered progress and could be abused to cover up fraud and ignorance. The best way to remedy the situation was to establish such society, which would unite those who were active in the field and as a result useful knowledge could quickly circulate.

It was also agreed at the conference to publish an annual journal for the activities. Only the first two volumes of the journal appeared in 1789 and 1790. Those who came to Skleny were interested in the scientific, technical, and economic side of Born's method. It was undoubtedly due to Born's forethought and organizational talent that they examined jointly the problem at hand. Born asked the assembled foreign specialists to give their views on the comparative advantages of amalgamation and smelting of silver ores. The collection of answers and comments was made public in 1787. They contain a generally favourable assessment of the method supported by technical and economic analysis and figures, as utilized by Born.

The plan was published in the first volume of the periodical of the Society, *Bergbaukunde,* which appeared in 1789 under the joint editorship of Born and Friedrich Trebra (1745-1819) a German mining expert active in the Harz and Saxon districts. This volume also contained a lengthy unsigned addendum discussing in more detail the objects of the Society and the involvement of its members. Volume 2 of *Bergbaukunde* appeared in 1790. A year later Born died. The French Revolution already stated in 1789 followed by the Napoleonic Wars and the Society of Mining Science fell in obscurity. It was after more than one hundred years later that mining and metallurgical engineers started to organize themselves into national societies that publish technical periodicals regularly.
Born was born in Carlsburg (or Karlsburg) the modern town of Cluj in Transylvania (also known as Siebenbürger, the western part of present day Romania), at that time part of the Austrian Empire. He was educated by the Jesuits in Vienna and then studied law in Prague. He travelled in Germany, Holland, and France studying mining. Born devoted his energy to the cause of Enlightenment. He had acquired international reputation as a mineralogist. The mineral bornite, CuFeS₂, was named in his honor by the Austrian mineralogist Wilhelm Karl von Haidinger (1756-1797). He regarded the acquisition and dissemination of scientific knowledge and organized scientific activities to be a key to progress. Beside his famous book on amalgamation, he also published:

- *Index Fossilium quae collegit, et in classes ac Ordines dispositit*, 2 volumes, Prague, 1772, 1775
- *Catalogue Méthodique et Raisonné de la Collection des Fossiles de Mlle Éléonore de Raab*, 2 volumes, Vienna, 1790.

It was primarily due to Born's endeavours that between 1769 and 1774 a group of scholars in Prague began to function as an organized Private Learned Society, which later became the Royal Bohemian Society of Science, that gave rise to the Czechoslovak Academy of Sciences in 1952. Six volumes of its journal, entitled *Abhandlungen einer Privatgesellschaft in Boehmen zur Aufnahme der Mathematik, der vaterländischen Geschichte, und der Naturwissenschaft*,³ appeared between 1775 and 1784 under his editorship. He also edited the *Physikalische Arbeiten der einträchitgen Freunde in Wien*,⁴ with two volumes appearing in 1783 and 1786. Remarkably, this purely scientific journal was published under the auspices of the Masonic Lodge in Vienna, which had assembled the intellectual and social elite of the capital, and was presided over by Born. His basic philosophy was that human progress was linked to freely accessible scientific knowledge, and in order to diffuse it he was prepared to utilize even a supposedly secret fraternity.

The new gold rush

The new gold rush in Latin America was triggered in January 1980 in Brazil when a gold panner found gold in Serra Pelada, in the Amazon region. Immediately, the unpopular military Brazilian government intervened to create the first artisanal mining reserve and encourage people to move to Amazon. About 80,000 men moved in to produce about 90 tons of gold from a single open pit about 1,000 m long, 500 m wide, and 100 m deep. All material exploited from the pit was manually conveyed in bags to be treated in thousands of different processing plants. All of them using mercury to amalgamate the whole material or sometimes the gravity concentrate. At present, the open pit is flooded.

In 1990, around 2,000 mining sites were worked by artisanal miners in the region producing about 100 tons of gold. At the same time, all military governments in Latin America adopted a similar attitude aimed at producing enough gold to cover their high external debt and at the same time to justify gigantic infrastructure investments.

Figure 16 - An artisanal miner recovering gold by amalgamation with mercury.

³ A Treatise of a Private Society in Bohemia for the Undertaking of Mathematics, the History of Fatherland, and Natural Science.
⁴ Physical Works of the United Friends in Vienna.
projects. The largest artisanal district in Latin America is located in the Tapajos river with about 460 "garimpos". Over 500 tons of gold were produced in this region during the period 1980-1997.

Although the use of mercury to recover gold is no longer used in the North America about 10 million people today are involved directly in artisanal gold mining worldwide using this technology. Of these, about 1 million are in Latin America. Figure 16 shows a miner handling the amalgam. Their annual production is about 200 tonnes of gold (Table 2) with a corresponding 200 tonnes of mercury emitted in the environment every year. Since the beginning of the new gold boom in these countries at the end of the 1970s to the present (1997), around 5 000 tons of mercury have been discharged into the forests and urban areas. This discharge of mercury occurs in three steps:

- Contaminated tailings (~ 20%)
- Evaporating mercury from the amalgam containing 30-40% Hg in open pans using a torch to separate gold in form of a sponge containing about 2% Hg (~ 70%)
- Melting of the gold sponge to produce an ingot (~ 10%).

Table 2. Estimated annual gold production in Latin America.

<table>
<thead>
<tr>
<th>Country</th>
<th>Gold (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>30-50</td>
</tr>
<tr>
<td>Colombia</td>
<td>20-30</td>
</tr>
<tr>
<td>Peru</td>
<td>20-30</td>
</tr>
<tr>
<td>Ecuador</td>
<td>10-20</td>
</tr>
<tr>
<td>Venezuela</td>
<td>10-15</td>
</tr>
<tr>
<td>Suriname</td>
<td>5-10</td>
</tr>
<tr>
<td>Bolivia</td>
<td>5-7</td>
</tr>
<tr>
<td>Mexico</td>
<td>4-5</td>
</tr>
<tr>
<td>Chile</td>
<td>3-5</td>
</tr>
<tr>
<td>French Guyana</td>
<td>2-4</td>
</tr>
<tr>
<td>Guyana</td>
<td>3-4</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>1-2</td>
</tr>
<tr>
<td>Dominican Republic</td>
<td>0.5-1</td>
</tr>
<tr>
<td>Others</td>
<td>2-5</td>
</tr>
<tr>
<td>Total</td>
<td>115.5-188</td>
</tr>
</tbody>
</table>

The majority of mercury emitted is deposited near the emission source. The high content of organic acids in sediments and waters favors oxidation of the deposited metallic mercury. Soluble organic mercury complexes are transformed by microorganisms into methylmercury, CH₃Hg⁺, which is soluble in water and is rapidly taken up by species in aquatic environments. Symptoms of mercury poisoning are detected in miners, gold dealers, and people living near the emission sources. Communities who have fish as the main diet have shown high levels of mercury in blood. Artisanal mining is also associated with forest destruction, incorrect tailing disposal that silt up water streams, and numerous social problems.

The first evidence of mercury biocumulation in Amazon fish was reported in 1984 by the French oceanographer Jacques-Yves Cousteau (1911-1997) as a result of an expedition in 1982 in Serra Pelada. Brazil is not a mercury producer and imports around 340 tons annually. From 1972 to 1984, Mexico was the main supplier, and since then the Netherlands, Germany, and England, all non-mercury producers, are responsible for 80% of the mercury entering Brazil. Some banks buy only gold that has been purified by leaching with nitric acid. This has encouraged miners to dissolve mercury from the amalgam. Mercury in solution can be recovered by simple methods, e.g., precipitation with scrap iron, but the artisanal miners simply discharge the slurry into the water streams.
The Minamata disease

In the 1950s inhabitants of the industrial town Minamata in Japan suffered many deaths and disease which was attributed to eating fish contaminated with mercury from the nearby chemical factory (Figure 17). This situation alerted public opinion regarding the need to regulate industrial emissions. In the 1960s the metallurgical industry was severely blamed for its sulfur dioxide emissions; it was realized that most sulfide ores contain traces of mercury and this mercury is volatilized with the SO$_2$. If this SO$_2$ is emitted in the atmosphere, the mercury will contaminate the environment. If it is made into sulfuric acid and the acid is used to make fertilizers, there is the possibility that mercury may enter the food chain. In the 1970s processes were developed in the Scandinavian countries to remove and recover mercury from these gases. Today all metallurgical plants treating zinc sulfide ores in particular, have adopted this technology. Figure 18 shows one of these installations.

Epilogue

From ancient times minerals of mercury, lead, and arsenic were known to be toxic to miners. For example, Marcus Vitovius the architect and engineer under Emperor Augustus, was familiar with the toxicity of lead and observed that the labourers in the smelters have pale complexions because of their prolonged exposure to lead dust and vapor.

Mining and the medical profession may seem to be far apart, but in reality they are closely related. Georgius Agricola who studied medicine at the universities of Bologna, Venice, and Padua, and who was appointed physician at the Joachimsthal in Bohemia in 1527, then at Chemnitz in Saxony from 1533 on, then became mayor of Chemnitz wrote a series of books on mining and metallurgy that remained in use for over two hundred years. The mysterious "miners' sickness" at Joachimsthal in the sixteenth century could now be attributed to the presence of the new metal, uranium, in the silver ore. The discovery of X-rays led to the discovery of the phenomenon of radioactivity of pure uranium salts which in turn led to the discovery of the intense radioactive metals polonium and radium in uranium ores. Needles filled with a radium preparation were used for treating cancerous tumors till the availability of the cheaper radioactive isotope of cobalt after World War II.

Another medical doctor, Giovanni Antonio Scopoli wrote among other works, an important metallurgy book in 1789. The first book on the relation between metal mining and miners' disease was written by Paracelsus in 1527 followed by Ramazzini in 1700. In modern times, physicians are becoming more and more involved in monitoring, diagnosing, and treating personnel working in such industries as asbestos, cadmium, beryllium, lead, etc., an area of medical science that became known as "Occupational Health". The presence of traces of arsenic in drinking water is also of major concern in many countries.
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