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By-product Elements and Coupled Elements

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6 By-product Elements and Coupled Elements

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This chapter discusses the aspect of by-product elements and/or coupled elements and potential production and supply risks.

By-product elements are produced as a minor product in the production process of a main element like copper, zinc, lead, nickel, aluminum, or iron. Essentially, the mining, processing and refining of the carrier element determines the maximum available production capacity. The global processing capacities of by-products are limited, and the potentials of extraction are not always fully utilized by current methods. Frequently, for by-product elements like the electronic metals indium, germanium, and gallium a shortage in the technical supply is maintained since their availability cannot be easily adjusted to an increase in demand. Increasing the production of the by-products would be achieved by increasing the production of the carrier elements or by extending the extraction capacities within an established production route. Moreover, the supply could be enhanced by processing currently untreated ores and concentrates as well as by treating residues from mining and processing.

Coupled elements like the rare earth elements (REE) and the platinum group (PGM) elements have to be mined and processed together. Typical for coupled elements are balancing problems. Each element is extracted in different quantities depending on the quality of the ore body, which is rarely in tune with the quantities required by the market.

6.1 Introduction

The Raw Materials Supply Working Group in the Directorate General Enterprise and Industry of the European Commission identifies 14 raw materials as “critical” in their report “Critical Raw Materials for the EU”. Most of them are produced as by-product elements and/or coupled elements, i.e. they are produced as a minor product in the production process of the main element like e.g. copper, zinc, lead, nickel, aluminium, or iron. Mineral raw materials like gallium, germanium, tellurium, selenium, and indium are produced exclusively as by-products. Gold, silver, tantalum, the platinum group elements, the rare earth elements, niobium, and cobalt are mined and processed as by-products or main products. For example, at least 14% of the world gold production comes from the mine production of copper, the platinum group elements, nickel, or lead/zinc, or about 50% of the silver production derives from the mining of gold, copper, nickel, and lead/zinc. Tantalum comes as a by-product of tin, however, the larger portion of the world tantalum production is mined as main element from tantalum ores. The rare earth elements (REE) as well as the platinum group metals (PGM) elements occur in compounds and be mined solely as coupled elements, i.e. single rare earth elements like dysprosium or neodymium cannot be mined individually.

6.2 By-products

By-product elements are both economically and technologically valuable minor elements, or "impurities", which are recovered from the ores of the carrier metals. Whilst the carrier metals occur within percent ranges in the ores the by-product elements generally occur in ppm ranges (Wellmer 2008). For instance, germanium occurs in zinc ores, gallium in bauxites, indium in zinc, copper, or tin ores, tellurium in copper ores, hafnium in zirconium ores, and tantalum in tin ores (cf. fig. 34). Neither reserve estimates nor the frequency of occurrence in the earth crust yield a meaningful indication for a future supply.

Frequently, for by-product elements like the electronic metals indium or germanium a shortage in the technical supply is maintained since their quantity depends on the quantity of the carrier elements extracted, processed, or refined. Hence, their availability cannot be easily adjusted to an increase in demand. Thus, an increase in supply is only possible via an increase in mining/extracting, processing, or refining of the corresponding major metal.

The prices of the minerals that are produced as by-product elements are scarcely affected by macro-economical parameters. The price developments are determined by the supply and demand of the commodity and by the particular trends in technology. It is typical for by-product elements to show long periods of over-supply with relatively constant low prices which alternate with short-time high price peaks and shortages with high demand - or expectations in demand - due to technical innovations. The duration of the intervals is hardly predictable. This is illustrated for the case of tantalum in figure 1.

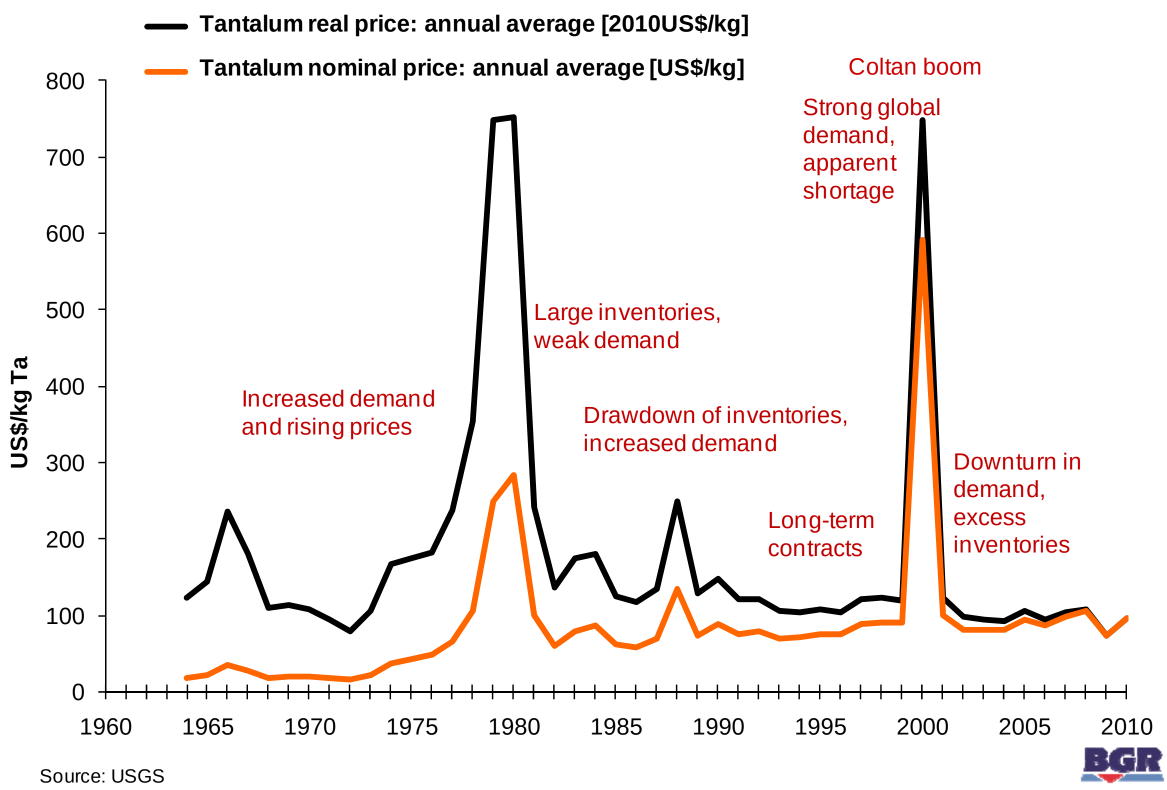

Figure 1: **Tantalum published spot prices (U.S. Geological Survey (USGS)). The long-term annual tantalite spot price have shown long-term stability, interrupted by very sharp price jumps due to concern in the tantalum industry and based on strong demand and fears about shortage.**

6.3 Coupled elements

Coupled elements like the platinum group metals (PGM, ruthenium, rhodium, palladium, osmium, iridium, and platinum) or the rare earth elements (or lanthanides, 15 elements i.e. europium, samarium, cerium, neodymium, dysprosium, etc.) typically occur together because they are situated fairly close together on the periodic table, their chemical behaviour is quite similar, and in geological formation processes they are precipitated collectively (Wellmer 2008). Hence, they have to be mined/extracted and processed together. Every deposit type has a typical relationship of the coupled elements in the group. For instance, the “lighter” rare earth elements occur considerably more frequently than the “heavier” ones. The lighter rare earth elements lanthanum, cerium, praseodymium, and neodymium account for more than 90 % of the total rare earth resources, the other 10 % share samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium. There is no carrier element as there is in the case of by-product elements. The grades within a family range in the same scale or at the most within the order of magnitude.

Typical for coupled elements are balancing problems. Each element is extracted in different quantities depending on the quality of the ore body, which is rarely in tune with the quantities required by the market. Generally, there is an element within a group or family that pushes the production. In the case of the PGM usually platinum is the leader, while in the case of the REE it used to be europium, then samarium and cerium, and now it is rather neodymium. The other end of the rare earth element spectrum can be but sold in small quantities at low prices or has to be stockpiled (Wellmer 2008).

Commodity markets are regulated primarily by demand. Generally, the demand shows a cyclical pattern, which is reflected in price trends. The establishing of new technologies can entail a change of the demand situation and result in a supply bottleneck. For most of the by-product and coupled elements there is likely an increasing demand, because they are essential for the high-tech industry, the automotive industry, and new technologies. Since the supply of the by-product and coupled element metals depends on the production and demand of the major elements they are subject to their market conditions. Substantially, mining and processing are aligned to recover a maximum output of the major elements, but a decline in prices or an oversupply can cause a production cutback, what consequently affects the production of the by-product and coupled elements.

By-product or coupled element metals can have a strong economic impact on the value of the major metal. In times of highly fluctuating world market prices the profitability of a mine can depend on the by-product and coupled element metals.

The co-production of by-product elements depends on the deposit and ore body type as well as on the extraction and treatment method. For instance, with the primary production of nickel from sulfide or laterite ores a considerable amount of by-product or coupled elements are jointly produced in the metallurgical process, i.e. copper, PGM, cobalt, also gold, silver, selenium, tellurium, and iron. In the mineralogical paragenetic versatile composed sulfide ores, in addition to nickel, the entire range of the above-mentioned elements which are industrially used occur, while from the mineralogically homogenious laterite ores besides nickel only cobalt is extracted. The iron in the lateritic ores will only be extracted when pyrometallurgical methods are applied in order to win ferronickel and nickel matte.

The production of tellurium depends on the processing and treatment method. Generally, tellurium is enriched in sulphidic ores, in which it preferably forms tellurides with precious metals. Mainly, tellurium is produced (~ 90%) as by-product in the electrolytic refining process of smelter copper. The output is reduced by the increasing application of heap leaching followed by solvent extraction/electro-winning (SX/EW), because this method does not allow winning tellurium. Another example for tellurium production is the Kankberg mine in Sweden, which commenced its production (gold and tellurium) in 2012. It aims to produce about 10% of the global tellurium production, which will be sold by a long-term contract fat a fixed price of 280 US$/kg.

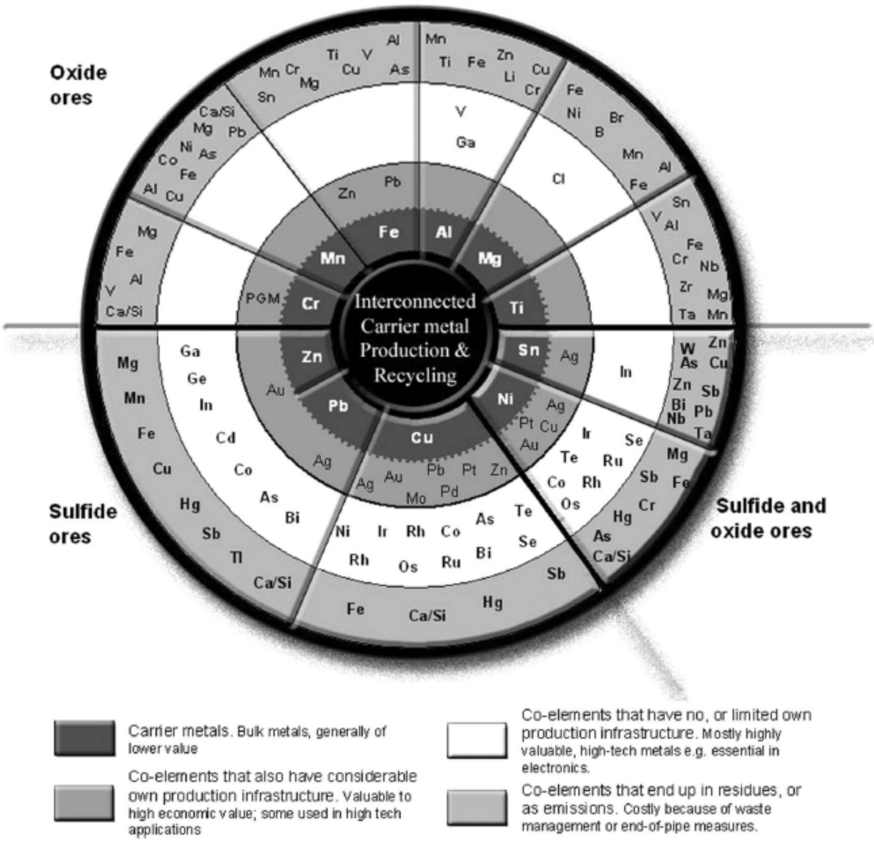

Figure 2: The metal wheel shows the paragenesis of metals in deposits (Reuter & Verhooef 2004). In the inner circle are depicted the carrier or major metals, in the other circles the potential co-elements are listed. Moreover, the elements shown in the outer circle can be by-products in residues or emissions, whose waste management can cause additional costs.

6.4 Indium as an example

Indium is exclusively won as by-product from conventional mining. With a geological abundance of 0.05 ppm in the continental crust (corresponds 50 mg per ton of rock) it is a comparatively rare element. Indium can occur in a broad variety of different deposits. Due to comparatively low grades, indium occurs always as a trace element and can be won as by-product under the appropriate economic conditions. More than 95 % of the indium supply derives as a by-product from the processing of sulfidic zinc ores. Indium is also contained in tin and copper ores. The main producers of primary indium are zinc smelters employing the electrolysis process. In 2009, around 150 million tons of zinc ores were mined (11.5 m t of zinc content). Assuming an average indium content of 10 ppm (10 g per tonne) in the mined ore (~7.5 % Zn cont.), the indium recovered amounts to 1,500 to 1,600 t. A lot of zinc smelters lack the technical equipment to treat the metal-rich residues, or the economic infrastructure for recovering indium quantitatively, so that they are often sold to other smelters that dispose of the adequate treatment facilities. Therefore, only a few countries provide the primary indium supply. The countries with the highest refined production of indium are China, the Republic of Korea, Japan, Canada, Belgium, and Peru. More than half of the global indium production comes from China.

For a long period of time, less than 20 % of the indium content was recovered from concentrates. The zinc processing industry viewed the production of indium and germanium as an unattractive business. To date, just 35 % of the 1,500 t of indium, which is globally available from indium-rich ores, is processed into indium metal (Mikolajczak 2009); 30 % of the indium-rich ores is not treated in highly specialized facilities, and of the remaining 70 % of the concentrates only 50 % is treated to recover the indium. The other half ends up together with other elements and impurities in residues. A number of plants have accumulated great amount of these residues over the years.

There are no reliable estimations on the global indium resources. For 95 % of the indium is recovered as by-product from zinc processing, an estimate of indium resources can at best be deducted from zinc resources. Only a marginal quantity of indium comes from the treatment of sulphidic copper and tin ores. The United States Geological Survey (USGS) indicates the global zinc reserves at 250 m t of Zn content and zinc resources at 1.9 bn t of Zn content. Assuming an average ore grade of 100 g indium per tonne Zn content and a recovery of 50 % will arithmetically result in 12,400 t of indium reserves and 95,000 t of indium resources. An average ore grade of 7.5 % Zn would contain less than 8 ppm indium on average. As a matter of fact, many sulphidic zinc deposits show considerably higher indium grades (Schwarz-Schampera & Herzig 2002), on average the indium grade is 10 to 20 ppm (Alfantazi et al. 2003). The indium reserves though used to be determined more conservatively since the economic production of indium required higher indium grades.

As of now, enhanced treatment technology and higher prices permit the production of indium from zinc, copper, and tin ores as well as other concentrates with grades of below 100 ppm. In recent years, the mine production of base metals has risen a good deal. The world-wide exploration revival of base metal deposits will account for developing new indium reserves. The high demand for indium has caused a bigger concern and a more active search for indium-bearing base metal concentrates.

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