MICA
Minerals Intelligence Capacity Analysis

DOCSHEET

Major metals and their companion metals metallogeny. The so-called 'by-products'

Mineral deposits frequently consist of a complex assemblage of major metals. Mining co-products and by-products are materials extracted in addition to the primary commodity. These may have some inherent economic value themselves.

Scope

INTRODUCTION

With rare exceptions, a mineral deposit is a complex assemblage of valuable products (present as sulfides, native elements, oxides) and waste material (silicates, carbonates, sulfates, …). The principal metal is commonly associated with a complex blend of co-elements. These can be other major metals that can be separated into individual processing streams or minor metals. These minor metals are typically found in such relatively low concentrations that they rarely form viable deposits on their own. They are recovered only as by-products during the processing of major metals. For example gallium is produced exclusively as a by-product.

Up to recent time, these co-elements were generally uneconomic to recover and were simply disposed of as wastes from mineralurgical and metallurgical processing. With the recent explosion of high tech products in which these elements are involved - as main component, alloys or traces – they can now have significant economic value.

The classification of a metal as a main product, co-product or by-product is normally based on the metal's relative value either in the mill feed or in the concentrate. The principal product is the metal with the highest value in mill feed, the co-product is the metal whose value is higher than 50 % of the main product, and a by-product is a metal whose value is lower than 50% of the main product (World Mineral Exploration: Trends and Economic Issues published by John E. Tilton, Roderick G. Eggert,Hans H. Landsberg, 1988, RFF Press).

COMMON BY-PRODUCTS

These co-elements may be present as mineral inclusions of mineral B in a host mineral A but more frequently as substitution in the structure of host mineral A. Substitiution can occur when elements have similar physical and chemical properties. For example, gallium can easily substitute for aluminium due to similar ionic radius. In cases of substitution, the distribution of the co-element within mineral A is generally complex and restricted to certain growth bands involving complex substitution rules. In sphalerite from Elmwood mine (Tennessee), Fe-Cd rich growth bands are alternating with Ge-, Ga-, Cu-rich bands (e.g., Bonnet et al., 2014).

The metal wheel (Verhoef et al., 2004; Reuter et al., 2005) offers a view of the link between main products and by-products (Fig. 1). Each carrier commodity metal is associated geologically with a unique and complex blend of valuable minor elements.

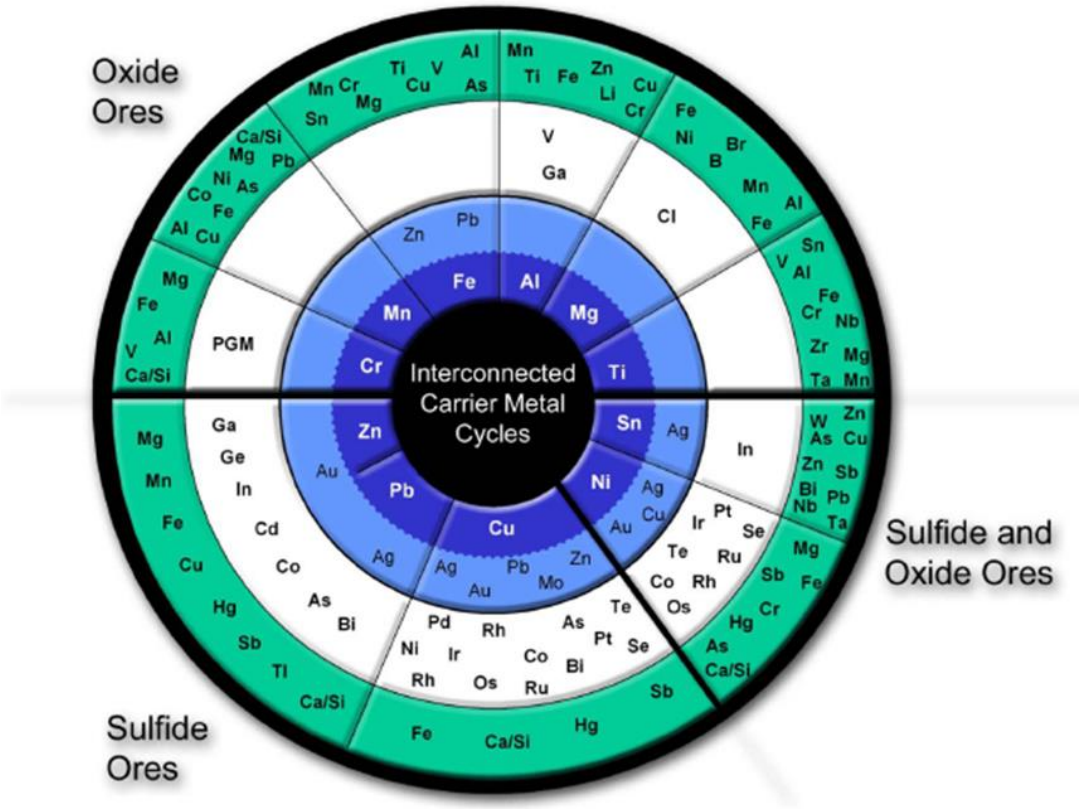

Figure 1: The "Metal Wheel" showing the relation between carrier metals (dark blue), co-elements that have their own production infrastructure (light blue), co-elements that have no, or limited own production

infrastructure (mostly highly valuable, high-tech metals) (white), and co-elements that end-up in residues, or as emission (green) (from Verhoef et al., 2004).

Among the large number of minor metal by-products associated with main commodities (Fig. 1), the most commonly recovered by-products are listed in Table 1. A more complete list has been recently produced by Nassar et al. (2015).

Main commodity	Deposit type	Possible by-product
Zn	Volcanogenic massive sulfide deposits, Mississippi-valley type deposits, Sedimentary exhalative deposits	Ge, In, Cd, (Ga)
Al	Bauxite	Ga, (Sc)
Cu, Mo	Porphyry copper	Re
Cu	Porphyry copper	Te, Se
Cr	Chromium Podiform deposits	Os, Ir, Ru
Cr, Ni (sulphide)	Chromium Stratiform deposits	Pt, Pd

Table 1: Example of the currently recovered by-products and deposits in which they are found.

Other examples include Sc which is present at a grade of less than 200 ppm in some Australian nickel laterite deposits. Co is also a common co-, or by-product of Ni from laterite deposits in New Caledonia. **Poland-based KGHM Polska Miedsz is consistently one of the world's top silver-producing companies, by recovering** Ag (30 to 80 ppm) as a by-product of Cu from the Kupferschiefer deposit.

China is by far the leading producer of several by-product metals (In, Ge, Ga…) mainly from ore coming from different parts of the world. Contrary to main products that are generally reported according to international standards, reporting of resources, reserves, and world production of by-product metals by each mining operation is quite uncommon and generally not made public (e.g., Nassar et al., 2015; Broadbent et al., 2015).

Contexts of use, application fields	-> contexts (e.g., environmental, economic, social assessment) -> which types of stakeholder questions are concerned? -> link to published studies that implement the method

► Not applicable

Input parameters	-> which parameters are needed to run the method

► Not applicable

Type(s) of related input data or knowledge needed and their possible source(s)	-> which types of data are needed to run the method, from which sources could they come… -> could be qualitative data or quantitative data, and also tacit knowledge, hybrid, etc.

► Not applicable

Model used (if any, geological mathematical, heuristic…)	-> e.g., geological model for mapping -> e.g., mathematical model such as mass balancing, matrix inversion, can be stepwise such as agent -based models, dynamic including time or quasidynamic specifying time series… -> can also be a scenario

► Not applicable

System and/or parameters considered	-> **the system can be described by its boundaries**. These can refer to a geographic location, like a country, or a city, the time period involved, products, materials, processes etc. involved, like flows and stocks of copper, or the cradle-to-grave chain of a cell phone, or the car fleet, or the construction sector, or the whole economy… -> **parameters** could possibly refer to geographic co-ordinates, scale, commodities considered, genesis of ore deposits and others…

► Not applicable

Time / Space / Resolution /Accuracy / Plausibility…	-> to which spatio-temporal domain it applies, with which resolution and/or accuracy (e.g., near future, EU 28, 1 year, country/regional/local level…) -> for foresight methods can also be plausibility, legitimacy and credibility…

► Not applicable

Indicators / Outputs / Units	-> this refers to what the method is actually meant for. Units are an important part but that is most of the time not sufficient to express the meaning. For example, **the indicators used in LCA express the cradle-to-grave environmental impacts of a product or service**. This can be expressed in kg CO_2-equivalent. But also in €. Or in millipoints. Or in m^2year land use. -> for foresight methods the outputs are products or processes

► Not applicable

Treatment of uncertainty, verification, validation	-> evaluation of the uncertainty related to this method, how it can be calculated/estimated

► Not applicable

Main publications / references	-> e.g. , ILCD handbook on LCA, standards (e.g. , ISO) -> can include reference to websites/pages -> references to be entered with their DOI

Bonnet, J., Mosser-Ruck, R., André-Mayer, A.S., Cauzid, J., Bailly, L. (2014). Germanium distribution in sphalerite from North-East America MVT Deposits: A multiscale study, Acta Geologica Sinica 88, 437-439. **DOI: 10.1111/1755-6724.12373_12**

Broadbent, C.P., Seltmann, R., Drielsma, J., Cox, M. (2015). By-product status: implications for reserve estimates (http://ec.europa.eu/DocsRoom/documents/14060)

Nassar, N.T., Graedel, T.E., Harper, E.M. (2015). By-product metals are technologically essential but have problematic supply, Science Advances 1, 1-10 (http://advances.sciencemag.org/content/advances/suppl/2015/03/31/1.3.e1400180.DC1/1400180_SM.pdf). **doi: 10.1126/sciadv.1400180**

Verhoef, E., Dijkema, G., and Reuter, M.A. (2004). Process knowledge, system dynamics and metal ecology, Journal of Industrial Ecology 8, 23-43. **DOI: 10.1162/1088198041269382**

Related methods	-> List of comparable methods, their particularities… -> link to one or several other existing fact sheet(s)

DocSheet '**Mineral deposit groups & types**'

Some examples of operational tools (CAUTION, this list is not exhaustive)	-> e.g., software… Only give a listing and a reference (publication, website/page…) -> **should be provided only if ALL main actors are properly cited**

► Not applicable

Key relevant contacts	-> list of relevant **types** of organisations that could provide further expertise and help with the methods described above.

► Not applicable

Glossary of acronyms /abbreviations used	-> Definition