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Mineral raw materials, concepts, upgrading and potential in Portugal

M.R. Machado Leite[a,b,*], A. Futuro da Silva[b]

[a]*LNEG - Laboratório Nacional de Energia e Geologia , S. Mamede de Infesta, 4466-91, Portugal*
[b]*FEUP - Mining Department, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal*

Abstract

This paper reports a key note for introduction the subject of mineral raw materials in the symposium Raw Materials, Processing and Applications, at the Material's 2013 Congress, that was held in Portugal in March 2013, promoted by Sociedade Portuguesa de Materiais (SPM). In the first part, some concepts about mineral deposit and technological upgrading of mineral raw materials are reviewed. Comminution is then presented not only as a typical size reduction process but also as a process that generates the liberation of mineral phases as a pre-requisite for mineral separation seen as size or grade Partition Processes. In the second part, information about the Portuguese potential for mineral raw materials, provided by LNEG Portuguese Geological Survey, is presented. Finally an overview about EC policy for Raw Materials and the Portuguese Government strategy for the mining sector is briefly explained.

Keywords: mineral raw materials; mineral processing; comminution; mineral liberation; mineral separation.

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1. Introduction

The fundamental problem of industrial mineral raw materials exploitation is the discovery of mineral ore bodies that host enough ore reserves with a quality above certain minimum metal grade, as well as the possibility of upgrading that original quality to meet the market demand. Those minimum metal grades are imposed by global markets offer and demand and depend on the scarcity of geological resources and on the technological development. These pre-requisites support the concept of Mineral Deposit and can be clarified thinking on the abundance of elements in the upper crust, on the minimum metal grades that allow the economic exploitation and on the metal grades demanded by the metallurgy or by the ultimate consumers. As it can be pointed out from Table 1, the formation of a mineral ore body in the crust obliged nature to produce a geochemical enrichment of 5 times for Iron, 200-250 times for Copper and Zinc, 1500-2000 times for Tin and Tungsten and more than 2500 times for Gold, relatively the crust average metal content.

Table 1. Abundance of elements in the upper crust, in the Mineral Deposits and in Mineral Concentrates

Elements	Crust average metal content (Clarke)	Ore Bodies minimum metal content	Concentrates average metal grades
Iron	5%	20-25%	60-70%
Copper	0.005%	1-1.5 %	25-55%
Zinc	0.003%	2-4%	50-60%
Tin	0.0002%	0.2-0.4%	60-70%
Tungsten	0.0001%	0.2-0.4%	60-74%
Gold	0.0000002%	0.0005%	---

However, even being exceptional geological formations, ores extracted from those mineral deposits are still too poor to be directly used by manufacturers, which obliges an intermediate technological step, referred as Mineral Processing.

* Corresponding author.
E-mail address: machado.leite@lneg.pt (M.R. Machado Leite)

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Also non-metallic industrial minerals and rocks (such as quartz, feldspar, clays, limestone, rock salt, ornamental stones), although frequent in the upper crust, are only exploited from very favorable geological formations and, even so, their natural properties (size, penalties, color, texture) should be improved to comply with market specifications.

2. Mineral Processing Technology

The principal unit operations of Mineral Processing (or Mineral Dressing) are comminution and separation and both contribute to the necessary ore upgrade.
This upgrading essentially involves controlling the size and the grade of intermediate and final products.

2.1. Comminution as a size reduction process

In a first step comminution promotes the alteration of the feed material size distribution, approximating it to the desired size for the final product – see Fig.1.

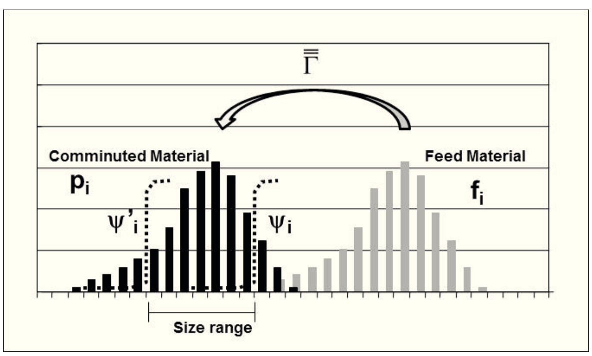

Fig. 1. Comminution as a Size Reduction process.

Comminution can be described as a transition process [1], being **Γ** the Size Transition Matrix. This matrix, as a function of size, is time dependent because comminution is a kinetic process and when it operates on the feed size distribution ($\mathbf{f_i}$), the size distribution of the comminuted product ($\mathbf{p_i}$) can be predicted as follows:

$$\bar{p} = \bar{\bar{\Gamma}} \cdot \bar{f} \qquad \text{(matrix notation)}$$

Because the desired product should be within a specific size range, sometimes between a maximum and a minimum, the second step is to promote one or more Size Separations after the comminution stage, which can be described by the application of one or two Size Partitions $\boldsymbol{\psi_i}$ and $\boldsymbol{\psi_i'}$, as shown in Fig. 1. In Fig. 2 the size composition histogram ($\mathbf{m_i}$) of the final product is represented.

$$\bar{m} = \bar{\bar{\psi'}} \cdot (\bar{\bar{I}} - \bar{\bar{\psi}}) \cdot \bar{p} \qquad \text{(matrix notation)}$$

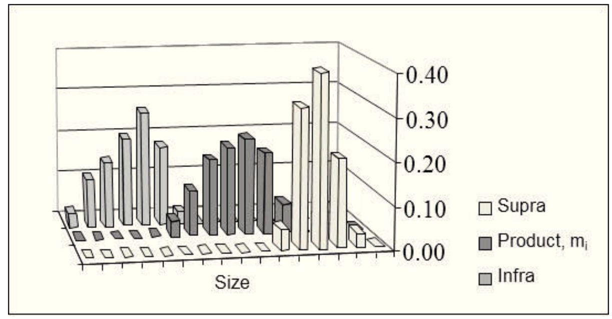

Fig. 2. Products of two successive Size Separations.

2.2 Particle liberation by comminution

In addition to being a simple size reduction process, comminution also promotes de alteration of particles grade. In fact, when a single particle is crushed into smaller ones, it happens that some daughter particles will be richer than the parent one and others will be poorer. Thinking on the particle grade distribution of a population, as shown in the Fig. 3, at gross sizes particles tend to have their grade around the population average grade, meaning that they are not yet liberated (histogram in dark grey) [2].

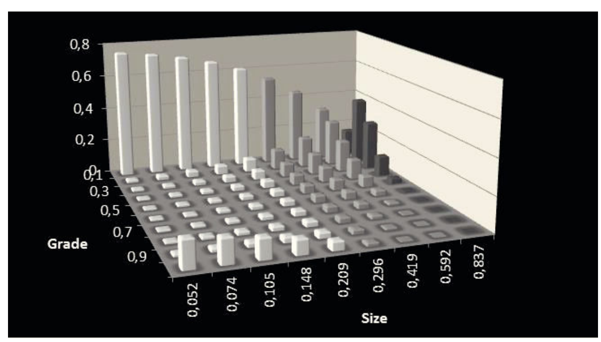

Fig. 3. Evolution of Grade Distribution with Size Reduction.

As far as comminution goes on, as already said, each particle generates richer or poorer daughter particles than itself and the grade histogram evolves from a bell shape to a U shape, meaning that liberation is increasing. This behavior can be introduced into the model by changing matrix **Γ** from a Size Transition Matrix to a Size_and_Grade Transition Matrix, when a Euler Beta Law form [3] is fitted to the particle grade distribution for a given size. In this case, beyond a single size reduction process as before, comminution is described as a liberation process.

2.3 Separation of liberated particles

Once achieved an adequate level of liberated particles at a certain degree of comminution (size range), the corresponding grade histogram allows reaching the targeted ore upgrade, in the sense that at lower degrees of liberation it is not possible to recover enough metal and higher levels of comminution do not pay the corresponding increased costs. The ore upgrading is then achieved performing a mineral processing separation (by applying a grade Partition Process) using physical methods, such as gravity separation (heavy media, jigs, shaking or vibrating tables, spirals, reichert cones, centrifugal jigs), magnetic separation (low and high intensity), electrostatic separation, froth flotation, or hydrometallurgical leaching processes.

The achieved upgrading level is evaluated by the metal grade and the metal recovery in the Final Concentrate of the whole process [4].

3. Economic valorization of mineral raw materials

The fundamental economic problem of mineral raw materials recovery is the appraising of ore reserves in order to ensure that the recoverable in situ metal content is enough to cover all the costs of ore exploitation and mineral dressing, as well as the costs of transport and smelting of the final concentrates.

This is explained by the well know equation for the mining economic benefit per ton of raw ore exploited and processed, **B** [5,6], where $\mathbf{P_i}$ and $\mathbf{a_i}$ are the market quotations and average grades of the valuable metals in the ore, $\mathbf{e_i}$ are the respective tailings average grades, $\mathbf{R_{pi}}$ are the process weight recoveries for each metal, $\mathbf{F_i}$ and $\mathbf{T_i}$ are smelter and transport costs and **L** and **M** are, respectively, mineral processing and mining costs per treated ton:

$$B = \sum_i a_i \cdot P_i - \sum_i (1 - R_{pi}) \cdot e_i \cdot P_i - \sum_i R_{pi} \cdot (F_i + T_i) - (L + M)$$

4. Mineral resources potential in Portugal

Despite being a small country, Portugal has a large variety of mineral resources (Fig. 4), which derives from the nature, complexity and recurrence of the main geologial processes that have affected the country - volcanism, magmatism, continental collision and intermediate periods of erosion and sedimentation. Associated with Paleozoic and older metamorphic and igneous rocks there are occurrences of typical metallic ores of Sn, W, Au, Ag, Zn, Pb, Li and U in the North and Center and of Cu-Zn massive sulphides in the Iberian Pyrite Belt (IPB) in the South, a well-known world class mining belt. Also interesting industrial mineral resources (feldspar, quartz, china clay, talc) and ornamental stones (marble, granite and black slate) occur associated with those geological settings.

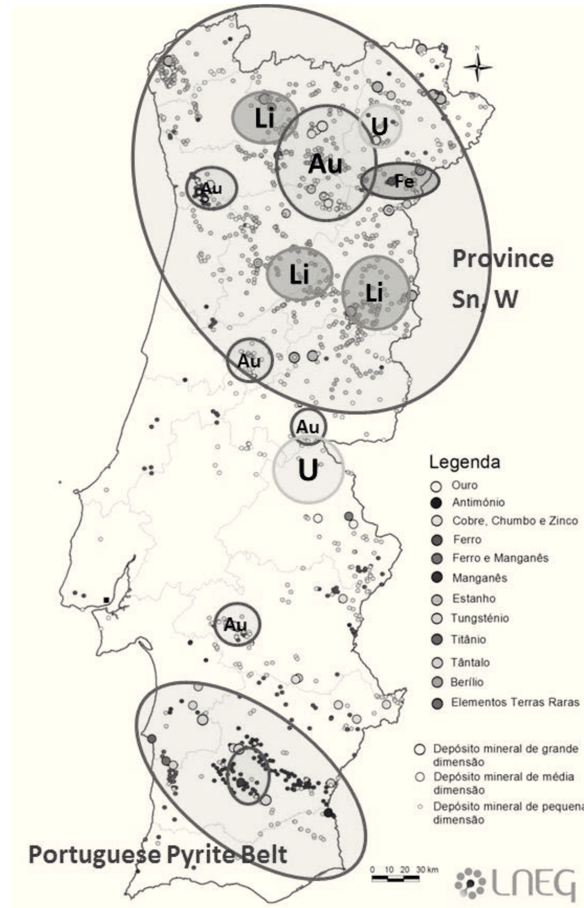

Fig. 4. Output of Mineral Resources Database – SIORMINP, LNEG GeoPortal – www.lneg.pt

In sedimentary terrains, of Western and Southern Meso and Cenozoic ages, there have been mining exploitations for gypsum and salt rock, special clays and other industrial minerals for the ceramics and glass industry, limestone for ornamental purposes, cement industry, chemicals and aggregates, diatomites and lignites, and rarely some metallic ores. The on- and offshore parts of these continental platforms are underexplored in terms of its petroleum geology and though prospecting have been done since the 70's, any finding of economic importance has been recognized until now.

In the Atlantic islands, Madeira e Azores and close sea floor, iron-manganese nodules (with cobalt) and hot springs with metallic rich sulphides have been under scientific research for some decades.

Remarkable for the Portuguese mining economy are the underground mines of Panasqueira in the tin/tungsten metallogenetic province and of Neves-Corvo copper/zinc in the national part of the IPB, both world class deposits that have remained working even during the long negative cycle of low metal prices before 2008. After the recent rising of metal prices, Portugal was able to attract prospecting enterprises for exploration of gold/silver, tin/tungsten, base metals, lithium and iron ores.

LNEG, acting as National Geological Survey, plays an important role as data provider and also as scientific and technological partner for industry. In LNEG GeoPortal [7] several on-line databases, geological mapping and other important data and information about mineral occurrences in Portugal are now available.

5. European policy for raw materials

After 1990 there was a strong decline of the mining industry in Portugal and all over the Europe. Only a few metallic mines survived in operation, but the non-metallic raw materials sector had profited from the growing of the building sector until de 2008 crisis. During this period the European market was supplied with commodities coming from third countries at low prices, while the access and permits for domestic mineral ore reserves exploitation in Europe was highly conditioned by environmental constraints.

However, when the 2008 crisis began, metal quotations raised significantly and Europe industry started to feel the existence of a real supply risk, namely because the "emergent economies" are now big consumers, which forced the European Commission to develop a policy for the sector. In 2008 was issue the document "Raw Material Initiative – meeting our critical needs for growth and jobs in Europe" [8], a strategy to ensure the access to raw material from international markets, to foster sustainable supply from domestic sources and to boost resource efficiency and promote recycling. In 2010 another document, "Critical Raw Materials for Europe" [9], was issued concluding that raw materials availability is increasingly under pressure and identifying 14 mineral raw materials falling in a cluster classified as having "*high relative economic importance and high relative supply risk*" (REE, PGM, Sb, In, Ge, W, Nb, Ta, Be, Co, Fluorspar, Graphite, among others).

Answering this challenge in Portugal, in 2010 LNEG developed an internal project to review its geological datasets and mineral occurrences databases, taking into consideration 14 metallic ores, 11 industrial minerals, uranium and coal, ornamental stones and 4 types of marine resources, in order to update the "in situ" mineral resources potential. This information was used by the Government to launch in 2012 the "National Strategy for Geological Resources – Mineral Resources (ENRG-RM)", an important policy resolution for the mining sector.

6. Conclusions

Mineral resources are an important source of wealth for the owner communities because they are comparative territory advantages. In addition, the domestic upgrading technologies for mineral resources valorization throughout the value chain are important contributors for job creation.

The Portuguese potential of mineral resources has a significant expression and can play an important role for the recovery of the economy, being realistic to think that, if the investments currently underway in the country are successful, the participation of the mining industry in the Portuguese GDP would duplicate.

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