IMPROVED ORE PROCESSING ASSESSED BY DIGITAL IMAGE ANALYSIS OF THE ORES: A KEY TO THE SUSTAINABLE DEVELOPMENT OF THE IBERIAN PYRITE BELT

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*Mining in the Iberian Pyrite Belt (**IPB**), the biggest VMS metallogenetic province known in the world to date, has to face a deep crisis in spite of the huge reserves still known after ≈5 000 years of production. This is due to several factors, as the difficult processing of complex Cu-Pb-Zn-Ag-Au ores, the exhaustion of the oxidation zone orebodies (the richest for gold, in gossan), the scarce demand for sulphuric acid in the world market, and harder environmental regulations. Of these factors, only the first and the last mentioned can be addressed by local ore geologists. A reactivation of mining can therefore only be achieved by an improved and more efficient ore processing, under the constraint of strict environmental controls. Digital image analysis of the ores, coupled to reflected light microscopy, provides a quantified and reliable mineralogical and textural characterization of the ores. The automation of the procedure for the first time furnishes the process engineers with real-time information, to improve the process and to preclude or control pollution; it can be applied to metallurgical tailings as well. This is shown by some examples of the IPB.*

Reserves of massive sulphides in the IPB can still reach some 1 000 mt, but their benefit has to face some difficult problems. Most of the *pyritic ores*, e.i. pyrite-rich and base metal-poor ores, are uneconomic for the recovery of base metals. The *complex ores* (e.i. those that contain base metals in the order of % units, as well as Au and Ag as by-products in the order of g/t) are usually fine grained and present complex intergrowths that make their processing haphazardous. The same happens with the *gold ores*, which are usually pyrite rich and contain very fine grained or refractory gold. As a result of continued research, some other types have been identified in the last years as potentially economic: *the primary copper rich ores* ("cobrizos primarios"), the *secondary copper sulphide bodies*, the *stockwork gold and cobalt bodies*, and the sulphide bodies with *disseminated gold*.

One of the important problems for the benefit of base metals is the fine grainsize of the complex ores, as a consequence of which their benefit was delayed until the late seventies: the ores were then milled to sizes of ~ 20 µm. Further improvements allowed to increase this size, e.g. to ~ 65 µm in the last years of the Almagrera and Aznalcóllar-Los Frailes mines. Other problems are the high content of pyrite, up to 80% of the ores, the textural complexity of the mineral intergrowths, and the usually very low but widespread content of other elements interfering in the process, such as Ag, Sb, Bi, Hg, Cd, and Se. All this leads to problems in the recovery or to poor quality of the base metal concentrates. Very fine milling produces an important fraction of ultrafine particles, lowering the performance of the floatation kinetics. Another problem, enhanced by fine milling, is the surficial oxidation of the particles, interfering in the flotatioin properties. Also a higher consumption of reactives, related to the higher specific surface of the fine particles. Or a lesser flotation selectivity, due to the similarity in the physico-chemical properties of the finer grains, as well as the loss of ultrafine particles due to mechanical dragging. The overall economy of the process will also be very unfavorable if fine milling cannot be avoided, due to the high energy consumption involved.

Ore processing can be improved in most of these aspects if the mineralogical and geometrical properties of the ores are quantified accurately and reliably. The volume of present-day operations precludes the use of traditional methods, e.g. point counting by an operator through the microscope, which are too time consuming. Optical, reflected light microscopy can still be very useful if it is combined with digital image analysis, DIA. Optical microscopy has been chosen instead of SEM in this case, because of its moderate price.

One of the most delicate steps for full automation is the successful reconnaissance of the ore minerals by the system and their reliable segmentation in any polished section. This is achieved in the Applied Microscopy Laboratory of the Engineering Geology Department, UPM, with a research 3 CCD colour video camera, which transfers the image from the Leica DMRXP microscope through a Matrox Meteor frame grabber to the computer with Aphelion software (*1*, *2*). Once the acquisition and identification of the mineral phases are granted, mathematical processing of the digital information can provide the quantitative data relevant to the problem under consideration: modal composition of the ores, grain size distribution of each phase, characterization and measure of the intergrowths, liberation grade of mill products, characterization of middlings, specific surface and other morphological parametres for each phase or type of middling, etc.

The statistical representativity of the ore samples to be studied with respect to the mill input and, at greater scale, to the ore extracted in the pit or to the deposit is a requirement to be established in each case. It was found out in the IPB that the relative uncertainty for each mineral increases as its abundance decreases, so that the number of measures should be established according to the confidence level required (*3*). Assuming a general Poisson distribution for the abundance of pyrite (the most common component of the ores), and following the "Guide to the expression of uncertainty in measurement" (*5*), the value for the coverage factor k=2 has been applied, so that the interval of a result, corresponding to a particular level of confidence, is expressed as: $Y = y \pm k\, u_c(y)$, in which y is the measured value, k is the coverage factor, and u_c (y) is the uncertainty associated to the measure y, or the relative uncertainty.

Based on 180 determinations realized on each mineralization at the Masa Valverde Deposit, IPB, $u_c(y)= 480$ has been estimated for a global mean of 545 (*pyrite*), so that a relative uncertainty of 0'1 (or 10 %) will require a number of fields measured (n) estimated as 310, applying the formula:

$$n \equiv \left(\frac{2 \cdot \sigma}{a_r \cdot \mu} \right)^2,$$

in which σ is the standard deviation, a_r the relative uncertainty, and μ the mean of the mineral phase. For other components, as chalcopyrite, sphalerite, galena and fahlore, the relative uncertainties and the corresponding number of fields have been estimated in the same way, but the number of fields to be measured to attain a high confidence level for base metal sulphides (which are scarcer, frequently below the 5 % modal abundance) would be unrealistic for traditional methods (e.g., 21 647 fields to limit to 0'1 the relative uncertainty for chalcopyrite). This enhances the need for automated methods, which can still be combined with qualitative or observational criteria (e.g. selection of sector of the deposit and type of the ore as defined by the geology) to improve the performance.

On the other hand, as the base metal ore contents are usually added and treated as single inclusive values (*complex ores*), the resulting total relative uncertainty may still be lowered. A critical evaluation of the methodology and of the results, supported by a comparison with the normative compositions obtained from systematic chemical analysis of the ore samples, is available (*4*). As a first step, rather than a perfect quantification of the whole orebody, the goal of the study is to produce, from the available data, a reasonably reliable picture of it, i.e. a preliminary information useful to the miner and whose errors can be constrained, at a low cost for the industry. Then the mineralogical quantification by DIA should progress in parallel with the definition of the deposit at the succesive stages, so that the information input for the processing plant pre-dates the input of ore.

As an example, a preliminary characterisation for the IPB ore types, based on modal analysis of the Masa Valverde ores by DIA, is presented. After segmentation, the modal ore compositions were processed to produce information useful to the geologist, the miner or the metallurgist, based on ratios of the main ore minerals (py = % pyrite, ccp= % chalcopyrite, sp= % sphalerite, gn= % galena, and td = % tetraedrite; gg = % gangue).

In order to characterize each type of ore, the *Complexity Index*, **CI**, was defined as the % modal ratio of the base metal bearing sulphides to the total sulphide content: *CI= 100 x (ccp + sp + gn + td) / (py + ccp + sp + gn + td)*. This is an intensive function, i.e. independent of the total quantity of sulphides or gangue, so it gives also an indication of the metal chemistry of the ore solutions, and can be equally applied to the massive sulphide (**MS**) and to the Stockwork (**ST**) bodies. Critical threshold values (3 %, 5 %) define the following ores: **P** (Pyritic): CI < 3 %; **B** (Base metal bearing): CI from 3 to 5 %; **C** (Complex): CI > 5 %. The six types defined (**PMS, PST, BMS, BST, CMS, CST**) are geologically meaningful, as they correspond to the compositions of real bodies (e.g. *Tables 1 & 2*, for BMS, CMS, BST and CST types, based on whole rock & ore analyses). They served to help sucessfully correlate the stratigraphy of the ores and check structural interpretations. This is particularly useful in bodies of very complex structure, as is usually the case in the SWIPB. On the other hand, this characterization has also a meaning for ore dressing and for a preliminary critical appraisal of the economic value of the orebody, i.e. for the miner and for the metallurgist (in connection with quantitative grain size analyses).

This way, DIA of ore minerals turns to be a very powerful tool to plan and check ore processing at the various stages of development of a mine. In other context, Australia, this technological process involving ore characterization, quantitative mineralogy, ore reserve evaluation, mine planning and ore processing is recognised as Geometallurgy. In the case of the IPB, it should be a key for the success of the most important project at present, dealing with the improvement of the current ore processing methods, and their innovation applying bioleaching, ferric oxidatioin, reduction roasting, etc. The research, at the pilot plant scale, includes processing concentrates the two biggest massive sulphide operations in SW Spain.

References

1.- Berrezueta, E. (2004). Caracterización de menas metálicas mediante análisis digital de imagen: investigación y diseño de un sistema experto aplicado a problemas mineros. Serie Tesis Doctorales. IGME. Madrid, España 360 p.

2.- Berrezueta E., Castroviejo R. (2006) Automatización de la caracterización microscópica de menas metalicas mediante análisis digital de imagen. Rev. Metal. Madrid (submitted).
3.- Castroviejo, R., Chacon, E., Múzquiz, C., Tarquini, S. (1999). A preliminary image analysis characterization of massive sulphide ores from the SW Iberian Pyrite Belt (Spain). Geovision 99. Internat. Symp. Imaging Applications in Geology. Liège, Belgium, 37-40.
4.- Castroviejo, R., López A. Múzquiz, C., Pirard E. (1999). Modal Image Analysis of metallic sulphides in core samples. A critical test of the metodology. Geovision 99. Internat. Symp. on Imaging Applications in Geology. Liège, Belgium. 41-44.
5.- ISO (1993). Guide to the expression of uncertainty in measurement. BIPM International Bureau of Weights and Measures, IEC International Electrotechnical Commision, IFCC International Federation of Clinical Chemistry, ISO International Organization for Standardization, IUPAC International Union of Pure and Applied Chemistry, International Union of Pure and Applied Physics, OIML International Organization of Legal Metrology.

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TABLE 1: Digital image analysis modal compositions of various Massive Sulphide and Stockwork orebodies (explanations and discussion in text): *whole rock analyses.*

	BMS (3<CI<5)	CMS (CI>5)	BST(3<CI<5)	CST (CI>5)
py (%)	72,80	74,92	6,96	29,52
ccp (%)	1,30	1,25	0,00	4,39
sp (%)	1,94	4,26	0,11	3,27
td (%)	0,02	0,07	0,05	0,02
gn (%)	0,09	0,50	0,07	0,02
gg (%)	23,85	19,00	92,81	62,78

TABLE 2: Digital image analysis modal compositions of various Massive Sulphide and Stockwork orebodies (explanations and discussion in text): *sulphide ore analyses.*

	BMS (CI<3)	CMS (CI>5)	BST(3<CI<5)	CST (CI>5)
py (%)	95.60	92,50	96,80	79,31
ccp (%)	1,70	1,54	0,00	11,80
sp (%)	2,55	5,26	1,53	8,79
td (%)	0,03	0,08	0,70	0,04
gn (%)	0,12	0,62	0,97	0,06