Modal Image Analysis of metallic sulphides in core samples.
A critical test of the methodology.

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Abstract

Modal analysis of ores is an essential tool for estimating reserves within a deposit and for determining the quality of the ore with respect to the chosen ore processing methodology. Optical image analysis is a fast and flexible technique for measuring the nature and amount of sulphides within a polished section. For sake of evaluating the quality of image analysis estimations in core samples from the Masa Valverde deposit, a correlation with chemical assays has been established. Average results per ore type indicate a very good agreement whereas a more detailed investigation of individual specimens points towards methodological problems. Errors generated by sampling, polishing and optical artefacts are reviewed and commented.

Introduction

Image analysis of ores has been applied for more than twenty years in mineralogical laboratories since it is the most straightforward method for obtaining essential data such as : modal analysis, grain size analysis, liberation coefficient, etc. In order to obtain maximum contrast between mineral species, many authors recommend using Back Scattered Electrons microscopy or even Energy Dispersive X-Ray mapping (Lastra et al.,1998).

A major problem with automatic image analysis quantification is to be able to assess the representativity and precision of the results. Statistics provide important tools for this purpose, but some problems cannot be solved this way, for instance those dealing with the physical preparation of samples or with a correct image acquisition. A direct comparison with the reality, when possible, may be of prime importance. But visual evaluation because of its subjectivity cannot be relied upon, so mineral balancing using chemical data is mandatory.

An empirical test has been applied to check the quality of quantitative modal analysis from several sulphide bodies obtained with the image analyser, by comparison with the chemical data obtained independently.

Materials and Methods

The ores discussed belong to the Masa Valverde deposit, Huelva, in the South West Iberian Pyrite Belt of Spain, and have been characterised through DIA (Digital Image Analysis) of 82 selected polished sections (Castroviejo et al., 1999) from 25 exploration boreholes cutting through the 500 m deep sulphide body. The chemical analysis, at 1 metre intervals, of all the intersections of the **DDH** (Diamond Drillholes) through the body were processed and converted into mineral values on a chemical basis (a sulphide "normative composition"), to obtain objective (chemical) values (CH-values) to be compared with the DIA-values.

The ores were classified into several types, according to the value of an empirical function called IC, which combines modal values of the main sulphides: pyrite (Py), chalcopyrite (Ccp), sphalerite (Sp), fahlore (most often tetrahedrite) (Td) and galena (Gn) (Castroviejo et al., op. cit). This classification has a geochemical / metallogenetic, as well as an economic / mining significance, as it relates to the base metal content of the ores, and consequently to their economic value and to the way they should be processed.

Pyritic, base metal-bearing and complex ores (respectively P, B, and C) are defined by an increasing value of their IC (< 3%, 3% to 5%, and >5%), and consequently of the base-metal content of the ores, whose main component is pyrite. According to their geological occurrence, each of them can be classified as either massive sulphide (MS) or as stockwork (ST) ores. MS and ST ores are geological concepts, but they can also be distinguished with the image analyser in function of their modal content of gangue minerals, usually silicates, which is low (<30 %) in MS and higher in ST. In total, six types of mineralisation can be distinguished: P_{MS}, B_{MS}, C_{MS}, P_{ST}, B_{ST} and C_{ST}. For practical purposes, B and C bodies can be grouped together, as BC_{MS} or BC_{ST}.
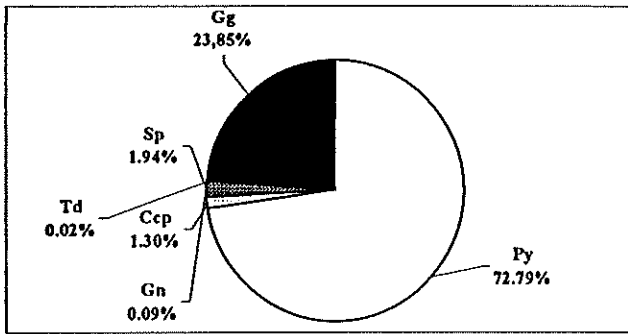
Results

Figure 1a. Average modal analysis of the total rock in the pyritic massive sulphide ore (P_MS) using image analysis.
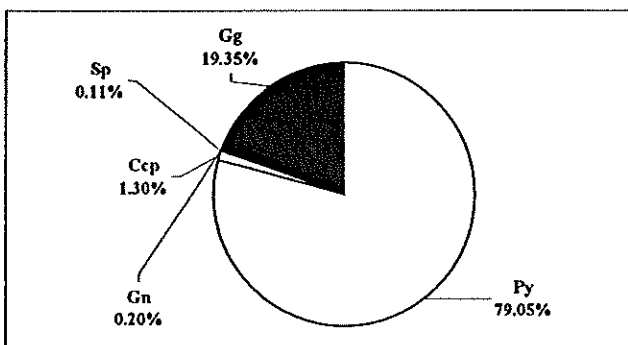

Figure 1b. Modal analysis of the total rock in the pyritic massive sulphide ore (P_MS) obtained through chemical analysis.

The comparison of the overall results obtained from the DIA- and CH-values shows a good fit for the classification of the samples into the various types of mineralisation, as well as for the average mineralogical (modal and normative) composition of the ores corresponding to various types (Figures 1 a/b., 2 a/b. and 3 a/b.).
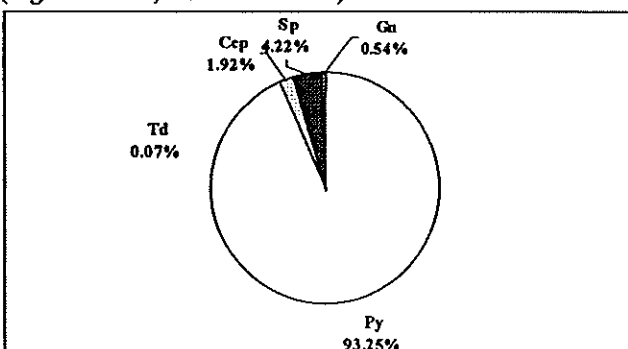

Figure 2a. Average modal analysis of the ore classified as complex massive sulphide (C_MS) using image analysis.
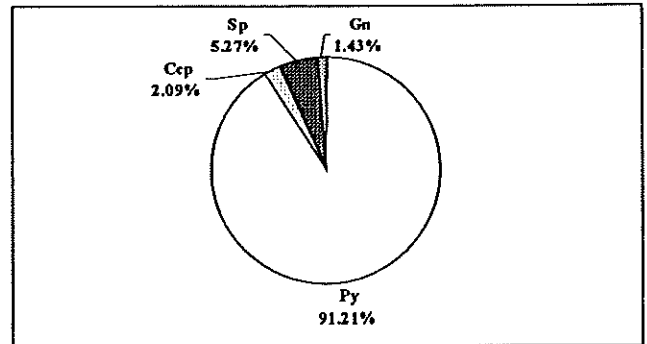

Figure 2b. Modal analysis of the ore classified as complex massive sulphide (C_MS) as obtained through chemical analysis.

Although this is satisfactory from the point of view of the methodology, there are still, when looking into details, some misfits to be explained. Figure 4. shows a good correspondence of DIA- and CH-values for an individual sample, whereas figure 5 indicates that this is not always the case.
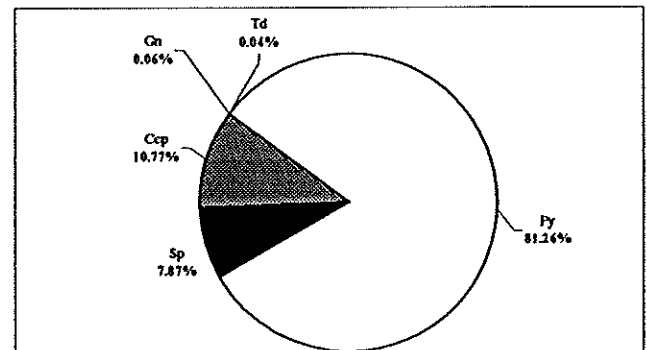

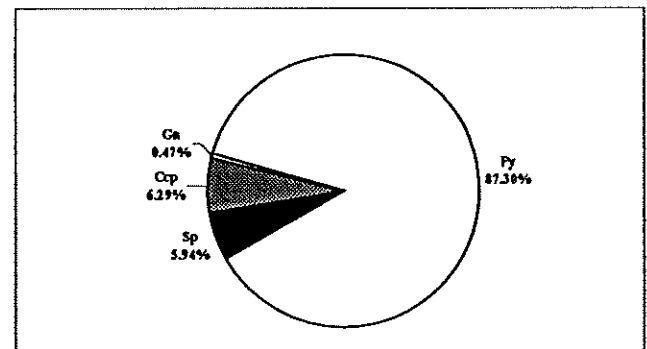*Figure 3a. Average modal analysis of the complex stockwork ore (C_ST) using image analysis.*

Figure 3b. Modal analysis of the complex stockwork ore (C_ST) obtained through chemical analysis.

A survey of such cases, even if they remain exceptional, must find a valuable explanation for these particular misfits, should the DIA method as a whole be retained as reliable. The polished sections concerned have been revised by a careful ore microscopy, and re-interpreted in terms of their visible ore composition, grain-size, quality of polishing, etc. At the same time, the chemical analyses of the different intervals have been revised and related to a careful

geological characterisation of the DDH-logs, particularly in terms of their homogeneity vs. heterogeneity, of the existence of oriented patterns, brecciation or ductile deformation, etc.
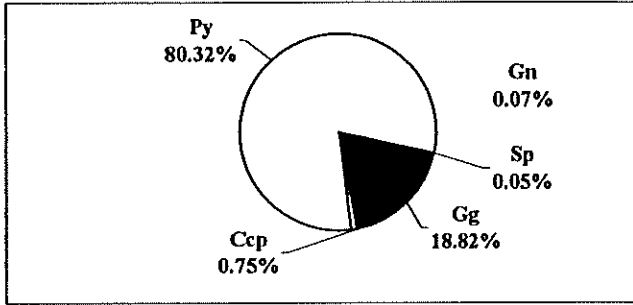

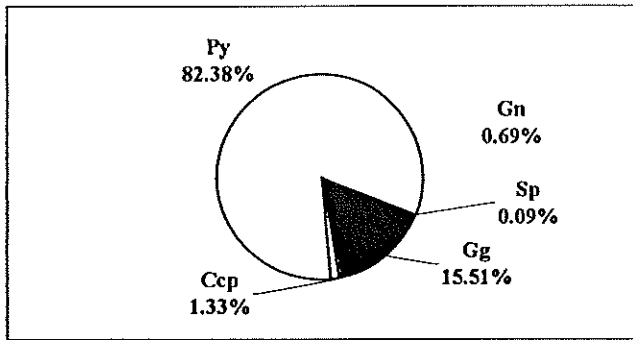Figure 4a. Total rock modal analysis from a single section (VA1 - 434.66) using image analysis

Figure 4b. Total rock modal analysis from a single section (VA1 - 434.66) using chemical data.

The influence of instrumental errors such as camera drift with time and thermal noise were limited to the minimum. Parameters such as feed power, temperature of lamp and camera, light intensity, were regularly checked for during the image acquisition procedure.
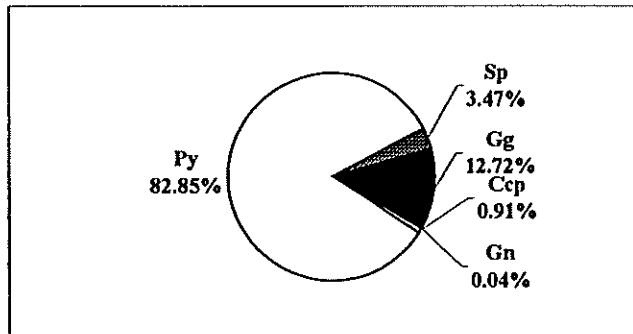

Figure 5a. Total rock modal analysis from a single section (VA15 - 573.25) using image analysis
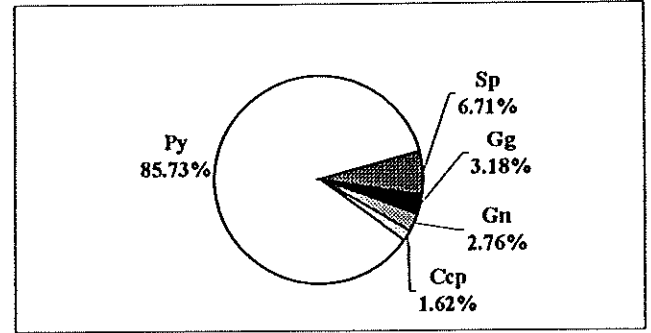

Figure 5b. Total rock modal analysis from a single section (VA15 - 573.25) using chemical data.

Interpretation of errors

The errors can be explained by one or several of the following causes:

Physical Factors.

- *Quality of the polishing :* a bad quality produces a lower reflectance. Consequently, sphalerite can locally be mistaken for gangue or galena for tetrahedrite, etc.
- *Pits due to polishing :* by enhancing the number of black pixels, this will increase the apparent contribution of gangue to the rock

This points out towards the importance of very careful microscopical preparation. Nevertheless, the errors induced by polishing artifacts can be dramatically reduced using a contextual filtering after image segmentation such as the one suggested in Pirard and Bertholet (1999).

Causes related to fabric.

- *Grain size:* If grain size is too fine, it will be beyond the resolution power of the microscope (or camera) and the relative abundance of minerals with medium reflectance can be artificially enhanced. The only alternative is to use high resolution cameras or to resort to higher magnifications. It must be kept in mind however that since we reduce the size of the sample (the image window) the variance of the modal analysis will increase, thus requiring a larger number of images in order to maintain the same precision in our estimates. The immediate result is to increase the analysis cost.
- *Porosity of the sample :* In the same way as bad polishing, porous samples lower the reflectance measured on the field.
- *Anisotropy of the sample :* Preferential orientations due to ductile deformation, sedimentary layering or banding, can bias the measurements if images are not taken at random.

Causes related to mineralogy :

- *Minerals with similar reflectance and color values :* in the present case there was no significant overlapping between the optical characteristics of the minerals. The segmentation procedure was previously tested and proved to be reliable, but in particular conditions, e.g. in cases of poor polishing, some failures are possible (pyrite could be mistaken with galena, and this ore with tetraedrite or with titanium oxides, etc.).
- *Minerals with varying composition:* in the "normative sulphide" calculations, chalcopyrite was considered as the only copper-mineral, while in the DIA tetraedrite was also measured, but its content beeing very small, no important bias is to be expected; on the other hand, the CH-values of pyrite can be overestimated, because sometimes (although rarely) some iron may be present as ankerite or siderite, having been attributed systematically to pyrite. The iron content of sphalerite ($<3\%$, as analyzed with microprobe) is to low to account for any significant bias in the DIA-values of pyrite.

Similarities between mineral reflectances in reflected light suggests that multivariate classification techniques should be used in the segmentation process rather than simple thresholding methods such as the one used here. The relative performance of several methods has been discussed elsewhere (Pirard and Bertholet, 1999).

Statistical factors :

- *Heterogeneity of the analyzed intervals :* (1 m of DDH), producing a distribution that cannot be observed at the scale of the polished section (2 cm x 2 cm), as happens frequently with breccias or very coarse ores. At a still larger scale, the stockwork mineralization is a very typical case, whose geometrical and mineralogical features cannot be correctly described with a few samples of 2cmx2cm.
- *A biased sampling of the ores :* This is a necessary problem in normal cases: while the sampling for chemical analysis is usually blind and systematic, ore sampling is done primarily by the geologist to recognize the orebody and its particular features, so mineralogical exceptions are likely to be over represented in the population sampled for microscopy. This means results likely to differ to some amount.

In order to reduce the influence of poor sampling, samples should be taken at random and the amount of material to be sampled should be defined in accordance with the textural characteristics of the ore (Gy, 1992)

Conclusions

The early DIA of massive sulphide ores, during the exploration drilling, may be a relatively unexpensive and powerful tool for the estimation of economic reserves and for a preliminary assessment of ore dressing problems, but it

must be always carried out under full awareness of the geological and statistical problems involved. The number of fields to be measured depends on factors such as grain size, relative abundance of the ores, precision required, etc.

Physical factors as simple as a good polish or the control of power, drift of the camera, etc. are the most frequent, and perhaps the most forgotten, challenge for a satisfactory DIA work. The most reliable results are obtained for relatively big bodies, i.e. as the average of a high number of measures, rather than in individual sections, as the mineralogical sampling may be conceptually biased. The ore microscopist must be fully aware of the critical problems of geology and scale involved. Even for big bodies, inhomogeneity (e.g. the stockwork geometry) can produce important biases.

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