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Usefulness of geological, mineralogical, chemical and chemometric analytical techniques in exploitation and profitability studies of iron mines and their associated elements

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Abstract

Due to the high number of variables involved in mine profitability studies, it is often very difficult to establish connections among them in order to provide a blend of market saleable quality products. In this sense, analytical chemistry together with chemometry are essential and indispensable disciplines to tackle these studies. The aim of this work was to demonstrate the utility of these disciplines to carry out optimization studies of iron mines. For this purpose, one of the most important iron mines of the Iberian Peninsula was chosen, sited in the mountain range of Sierra Menera, near the location of Ojos Negros (Teruel, Spain). Geological, mineralogical and chemical composition of 148 samples was analyzed, corresponding to different depths of three drill holes (named TE1, TE2 and TE3). In particular, aspects concerning to chemical composition are very important, since the mean contents of certain elements, such as phosphorus, sodium and potassium, should be restricted to the established limits to prevent that companies can drive back the raw material if they do not fulfil the necessary requirements. On the other hand, the large number of analysed samples drove us to use a statistical processing of the data. Among other aspects, it provides a way to find possible connections among a high number of variables and classify samples into compositional groups sharing similar composition, in order to limit the mineralised area and to obtain enough information about the amount of those chemical elements associated to iron ores. Data obtained from all these analytical techniques were in good agreement and provide a methodology that can be of wide interest applied to different geological studies.

Keywords: Iron ores; Phosphorus; Sodium; Potassium; Analytical techniques

1. Introduction

Iron is the fourth element more abundant in the nature. Its deposits are known from antiquity and they have been used in numerous applications. In this sense, Spain has been one of the word leading iron producers during the last part of the 19th and the first quarter of the 20th centuries (Zitzman and Neumann Redlin, 1976) and even nowadays, has abundant reserves of this element.

Several aspects must be taken into account to consider an iron deposit economically profitable, such as appropriate volumetric measurement, mineralogical and chemical composition, physical composition relating to the grain size and geographical location. In particular, aspects concerning to chemical composition are very important, since the mean contents of certain elements should be restricted to the established limits to prevent that companies can drive back the raw material if they do not fulfil the necessary requirements. Among these elements, the presence of phosphorus above a determined level increases the fragility of iron and steel products and forces the election of a particular industrial process. Then, there is a general trend to

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reduce costs avoiding the employment of mineralizations with high phosphorus contents. An iron mineral with a phosphorus content above 0.15% expressed as the corresponding oxide is normally driven back. Phosphorus could be also a problem if it is solubilised, since it could cause ecological impacts in surface waters (Haygarth, 2005, Haygarth et al., 2005). On the other hand, alkaline elements (sodium and potassium) produce complex carbonates, which are deposited in the refractory materials affecting the normal function of the blast furnace. In these cases, the maximum contents accepted by the different companies use to be between 0.22 and 0.45% expressed as K_2O+Na_2O.

Due to the high number of variables involved in mine profitability studies, it is often very difficult to establish connections among them in order to provide a blend of market saleable quality products. In this sense, analytical chemistry together with chemometry are essential and indispensable disciplines to tackle these studies.

The aim of this work was to demonstrate the utility of these disciplines to carry out optimization studies of iron mines that can be extended to other different studies in the chemical and geological fields. For this purpose, one of the most important iron mines of the Iberian Peninsula during the twenty century was chosen (Fernández-Nieto, 1977), sited in the mountain range of Sierra Menera, near the location of Ojos Negros (Teruel, Spain). Geological, mineralogical and chemical composition of 148 samples was analyzed, corresponding to different depths of three drill holes (named TE1, TE2 and TE3).

Geological and mineralogical analyses helped us to establish the lithologic columns of the drill holes and to know their vertical mineralogical composition respectively. In addition, mineralogical data were displaying using a Box and Whisker plot, a histogram-like method that helps us to interpret the distribution of data, and statistical and chemometrical analysis of them were carried out.

Chemical analyses allowed us to know the major constituents, as well as the contents of phosphorous and alkaline elements, according to the different zones, previously defined for each drill hole from a mineralogical point of view. Besides, the large number of samples analysed drove us to use statistical processing of the data. In this sense, correlations among the analytical variables were calculated considering in some cases all samples and in others those from the mineralised areas. Cluster analysis was carried out to establish groups of chemical and mineralogical parameters with similar characteristic. Supervised Pattern Recognition was applied in this study to those 71 samples corresponding to mineralised areas of TE1, TE2 and TE3 drill holes, considering the 8 chemical parameters as variables (Fe_2O_3, MnO, Al_2O_3, CaO, MgO, Na_2O, K_2O and P_2O_5). Discriminant analysis was used for hard classification, which provides a way to find possible connections among a high number of variables and classify samples into compositional groups sharing similar composition, in order to limit the mineralised area and to obtain enough information about the amount of those chemical elements associated to iron ores.

Finally, in a group of selected samples, observations made by polarization microscopy and scanning electron microscopy (SEM) equipped with an energy dispersive X-ray (EDX) analyzer, allowed us to distinguish and to classify different material types in relation to their texture and mineral composition.

2. Geological setting, mineralization and mining

The Ojos Negros mine complex is sited at a height of 1500 m.a.s.l. in the mountain range of Sierra Menera (NE of Spain, Fig. 1A). This mountain range is located from N-NE to S-SW direction and it constitutes the border between Teruel and Guadalajara provinces (Spain) (Fig. 1B).

2.1. Structure and stratigraphy

The ore body Tío Elías (Fig. 1C) is located in the slope NE of the Sierra Menera in the Ojos Negros mine complex near the foothills of Alto del Vicario, limited by Navarrosa sector and separately by a big break. The ore body is formed by strata-bound, surrounded with the sandstone and quartzite from the roof and walls. In the sides the croup out have faults (Fernández Rubio, 1976). The thickness of the orebodies is typically from less than 1 up to 10 m.

Topographically, it is also the watershed (Pico Lobo, 1538 m. a.s.l), in the eastern slope is sited the Ebro river basin and in the western slope the Tajo river one.

The basal portion of the stratigraphic sequence consists of quartzite and graywacke of Early Ordovician age with intercalations of sandstone and iron oolitic layers (Herranz et al., 2003). It is overlaid by a Late Ordovician carbonate dominated succession, known as the Pobo limestone (Villena, 1976) which are divided into three members: (i) quartzite and sandstone with silty intercalations, (ii) an irregularly distributed sequence of marble, shale and carbonate (Cabezo limestone) including Mg–Fe carbonates and (iii) dolostone, iron oxides and hydroxides and clays (Fig. 1C).

From the structural point of view, the Hercynian basement is composed of Precambrian to Permian rocks with preferred N–NW to S–SE directions (Fernández-Nieto et al., 1981). The intracratonic Iberian basin was developed during the Alpine orogeny (Tertiary) and initially filled by fluviatile clastic sequences.

2.2. Mineralization

Sierra Menera is a Paleozoic massif composed by goethite gossans formed from weathering processes (Villena, 1976). It is hosted by Ordovician and Silurian basement rocks (western of Iberian Range).

The strata-bound ore bodies are preferentially located on the flanks of Sierra Menera anticline. The Paleozoic strip is extended to the Almohaja (South) and Pobo de Dueñas (North) where several massifs crop out with about 35 Km long and 10 Km mean wide (Villena, 1976; Fernández-Nieto, 1977; Fernández Nieto and Arrese, 1979; Fernández Nieto et al., 1981, 2003). They are mainly composed of Mg–Fe carbonates (belonging to sideritemagnesite series) and dolomite, with a gangue of quartz, clay minerals and calcite. Mg–Fe carbonates at Sierra Menera occur as