MLA and optical microscopy as complementary techniques to the iron ore geometallurgical studies

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Abstract

Mineral liberation is an important variable to be considered in the iron ore geometallurgical studies, especially since it provides information leading to the understanding of the ore's behaviour in the beneficiation process, mainly when harder ores are concerned. Nowadays, the professionals and researchers in the mineral industry have been using complementary techniques for mineralogical characterization. In this way, Mineral Liberation Analyser (MLA) and optical microscopy are amongst the most efficient and important tools in these studies. Together, these techniques can provide information leading to the development of geometallurgical models, including the degree of quartz liberation, mineral modal composition, mineralogical association and particle and mineral size distribution, as well as the spectrum of mineral liberation either by free surface or particle composition. The purpose of this study is to compare the degree of quartz liberation in four different iron ore types observed in optical microscopy and MLA. It also assesses the influence of mineral liberation in the quality of the resulting concentrate, according to the SiO_2 content. All the results of the various quartz liberation degrees, determined by both MLA and optical microscopy were very close, as well as the correlation between the mineral liberation and the ore's response in the flotation process. The investigation provided evidence that the mineral liberation study is an important tool in the prediction of the ore's behaviour in the beneficiation process.

keywords: iron ore, mineral liberation, MLA, optical microscopy, geometallurgy.

1. Introduction

The gradual depletion in high-grade iron ores combined with many decades of extraction compelled the leading Brazilian mining companies to mine more complex ores in order to increase reserves and production rates in the last few years. Complex ores are, especially, the ones assigning low Fe content, increased impurities amount, and high hardness. The explotation of these ores results in greater difficulty in processing, mainly in the grinding stage and concentration process (Costa *et al*., 1998; Das et. al., 2007; Rocha, 2008; Rao *et al*., 2009; Rodrigues *et al*., 2014; Rodrigues, 2016). Harder ores usually require higher grinding energy, resulting in difficulties in achieving the mineral liberation needed for the flotation process, which affects the quality of the concentrate and the production rate.

Therefore, in an attempt to ensure high production rates and keep the desired quality of the products, professionals and researchers in the mineral industry have been working towards the development of tools capable of predicting the ore's behavior during processing. In other words, geometallurgical models are being developed.

Mineralogical characterization is one of the most important stages in the iron ore geometallurgical studies. Mineral liberation, more specifically the degree of quartz liberation, is an essential variable considered in the mineralogical characterization, since it can provide information towards the understanding of the ore's behaviour in the beneficiation process, mainly in regard to harder ores.

The mineral liberation is obtained from a reduction of the particle size by grinding (Taggart 1945; Beraldo 1987; Herbst 2002; Silva 2003; Wills 2007; Rosa 2013), representing one of the basic procedures in the flotation process (Peres 2007). The mineral liberation process is highly affected by the ore`s intrinsic characteristics, such as microstructure and texture of the rock, size and shape of the crystals, mineral associations, all resulting from the ore`s genesis process (Gaudin 1939; Porphírio *et al*. 2010; Ferreira 2013; Rodrigues 2016).

Gaudin (1939) was the pioneer in developing methods for measuring the liberation degree. His methods are amongst the most applied ones and they have been utilised by professionals and researchers within the scope of the mineral industry. Gaudin defined the liberation degree as being the proportion of free particles, composed by only one mineral phase, in relation to all particles in the ore -- free and mixed particles alike (composed by two or more mineral phases).

The degree of quartz liberation is usually calculated by visual estimation by using optical microscopy consisting of the counting of different categories of free and mixed particles, taking into consideration the proportion amongst quartz, iron oxides and hydroxides (Gaudin, 1939; Bérubé, 1984). This method presents the advantage of enabling geological interpretation during the analysis, making the distinction amongst the different types and aspects of the minerals in the ore possible, e.g. specular hematite and porous hematite, different types of goethites, and also the possibility to distinguish magnetite from hematite. Identifying these minerals in the mineralogical composition is vital when it comes to understanding the changes regarding the ore's behaviour during processing (Costa *et al*. 1998).

However, as in any method, visual estimation in optical microscopy presents some disadvantages. First of all, in order to have reliable results, the analysis must be done by an experienced professional and is a time-consuming process. The information is obtained by counting a limited number of particles, having low statistical representation considering the total number of particles in the polished section. Considering this aspect, Mantilla (2013) has demonstrated that 500 particles in each section is enough to provide a reliable result.

In the past few decades, the technological advance has enabled the rise of various analytical techniques. In the mineral liberation studies, the MLA (Mineral Liberation Analyser) and the QEMSCAN (Quantitative Evaluation of Minerals by Scanning Electron Microscopy) are two of the most applied techniques by professionals in the mineral industry (Sandmann 2015).

MLA is a software and hardware add-on SEM system. It is an automatized measurement tool used in mineralogy research. MLA was developed to mineral identification by combining BSE image with energy-dispersive X-ray spectrometry microanalysis and also to perform automated quantitative mineral liberation characterization (Fandrich 2007).

One of the greatest advantages of this technique is the large number of particles it can analyze, guaranteeing an excellent statistical significance. The MLA provides a lot of important information in mineralogical characterization, such as modal mineral composition, mineralogical association, particle or mineral size distribution, and the spectrum of mineral liberation by free surface or by particle composition. When it comes to studying iron ores, MLA presents some disadvantages. It does not distinguish hematite from magnetite and the morphological varieties of hematite and goethite.

Currently, these techniques have been used along with optical microscopy in mineralogical characterization, especially to measure the degree of quartz liberation in the iron ore studies.

This article aims to compare the values of quartz liberation degree of four different iron ore types observed through optical microscopy and MLA, and also to assess the influence of mineral liberation on the quality of the concentrate obtained, taking into consideration the SiO_2 content.

2. Materials and methods

2.1 Samples

For the current study, four samples of different iron ore types collected in Alegria's Mines, located in the eastern region of the state of Minas Gerais known as Quadrilatero Ferrifero, were selected. These samples differ from each other according to the ore genesis process, mineral composition, chemical quality and particle size distribution, or hardness level. Each sample was tagged "AGEO" (which stands for "geometallurgical sample" in Portuguese) and then sequentially numbered. The AGEO 1 sample corresponds to the soft ore composed by goethite, specular hematite and porous hematite, in approximately equal proportion. The AGEO 2 sample is a compact ore composed basically of goethite and porous hematite.

The AGEO 3 sample is similar to the AGEO 2 one, the only difference is that it is a semicompact ore. The other sample, AGEO 4, is also a semicompact ore composed essentially of specular and porous hematite (Figure 1).

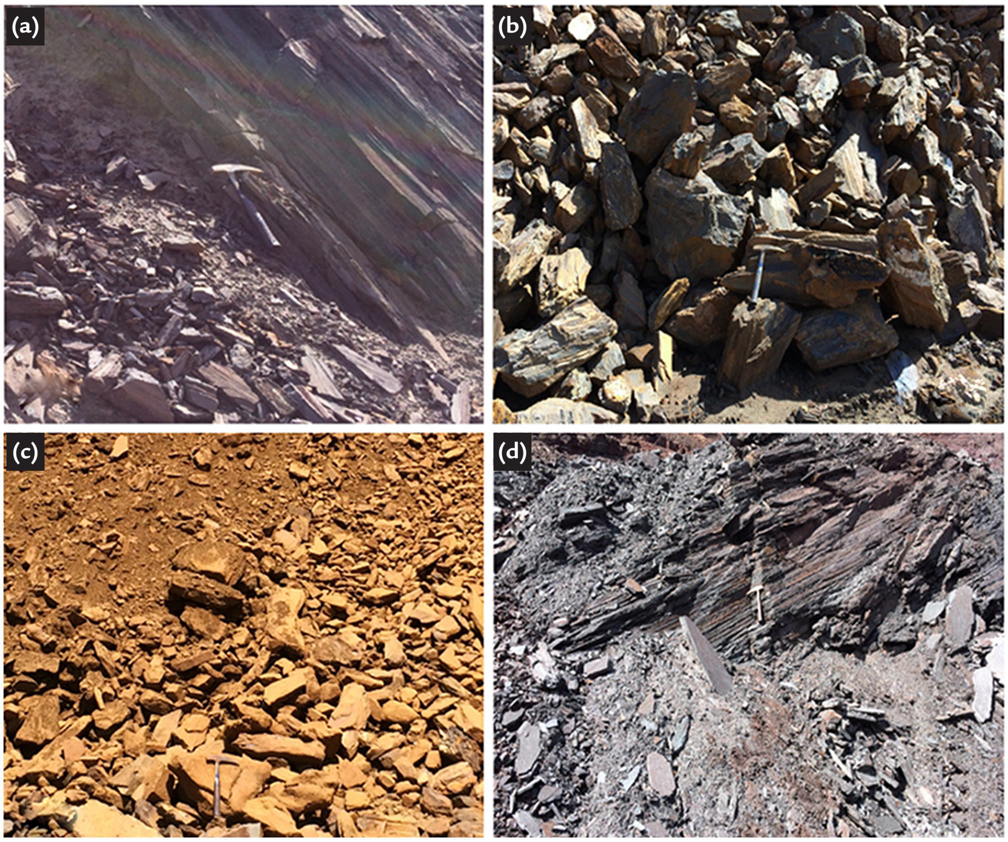

Figure 1 - Visual aspect of the types of ores studied. (a) AGEO 1; (b) AGEO 2; (c) AGEO 3 and (D) AGEO 4.

2.2 Methods

Each sample (3.0g) was submitted to a characterization process in a laboratory, as depicted in the flowchart in Figure 2. First, the samples were dried at 105°C and then submitted to size analysis, considering all the Tyler sieve series. After that, the samples were crushed to sizes below 9.5mm, and then ground until 90% of the total mass was below 0.15mm. The ground samples were deslimed in order to remove the particles smaller than 0.010mm. Then, the underflow was homogenized and quartered to achieve a content weighing (150g), which was submitted to chemical analysis and mineral characterization (including the measurement of quartz liberation degree). The remaining part of the underflow was submitted to a flotation test, with the use of a WeMo flotation cell of 2.4ml and rotation of 1.300 RPM; with percentage solids of 40% and pulp pH adjusted to 10.5. The reagents used were corn starch gelatinized with NaOH in the proportion 5:1, as depressor of the iron minerals, and a mix of decylethermonoamine and decyletherdiamine in the proportion 1:1 as collector of gangue minerals.

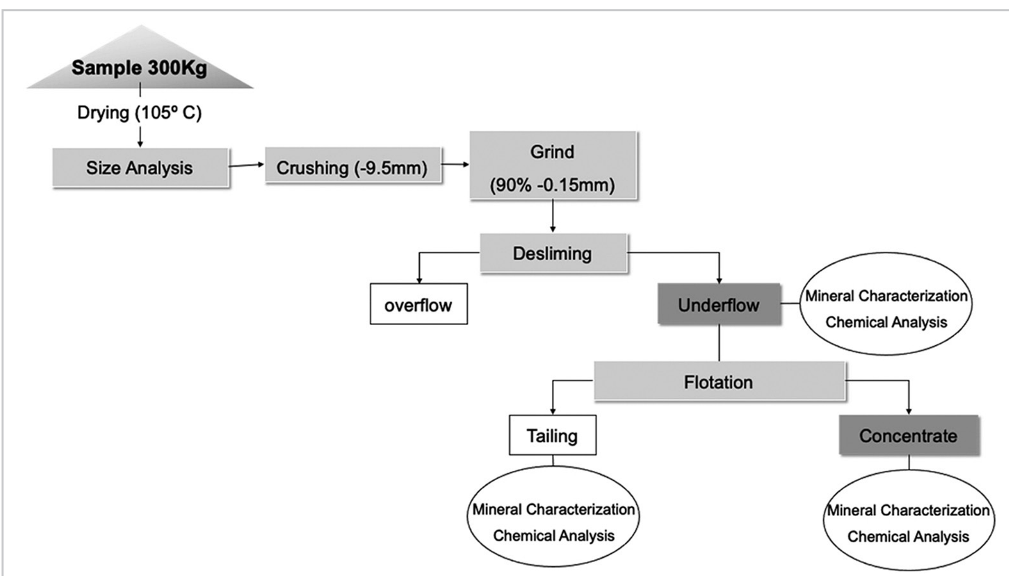

Figure 2 - Flowchart: characterization of the samples.

In this stage, the samples of the concentrate and tailings were obtained and then submitted to chemical analysis.

The degree of quartz liberation was measured through optical microscopy and MLA. It is very important to notice that the same polished sections were analysed by both methods. The polished sections were covered/coated with carbon for the MLA analysis.

The analyses by optical microscopy were done in accordance with the method proposed by Pereira (2009) based on Gaudin (1939) and Bérubé (1984) and described in detail in Rodrigues (2016). In short, the degree of quartz liberation is measured by visual estimation by counting 500 particles and separating them according to their different classes: free particles and four other types of mixed particles. These mixed particles were separated into subclasses according to the mineralogical composition of the particles, in other words, the proportion of quartz and iron-bearing minerals in the particle composition. The subclasses were defined according to the composition; between 10% and 50% of iron oxides and oxy-hydroxide in the particle, between 50% and 90%, and the remaining assigning over 90% of iron-bearing minerals in the particle. In this analysis, the particle considered as a free quartz particle is the one assigning over 90% of quartz.

The mineral composition of each sample was defined according to a standardized proportion (totalizing 100%) of the iron oxides and hydroxides, considering the morphological varieties such as specular hematite, porous hematite, goethite and magnetite.

The MLA analyses were done through the GXMAP method resulting in an Xray spectra in accordance with a grid pre-defined in all the phases separated by tones of grey and classified as goethite, hematite and quartz. Ordinarily, in mineral liberation studies, the data obtained in MLA analyses are used to create graphics of the liberation spectrum of quartz by composition class. However, the degree of quartz liberation can be calculated using the data table provided by the MLA in mineral liberation analyses by particle composition.

First, the free particles of iron minerals (more than 90% iron oxy-hydroxide in mineral composition) were not considered in the calculation, according to Gaudin's method. In the case of the mixed particles, the relative proportion of quartz in the mineral composition of this particle was considered.

In Table 1, an example of the calculation of the relative proportion of the mixed particles is presented. For the class between 10% < x ≤ 15%, the MLA counted 4 particles with the average proportion of 12.5% of quartz in the particle composition. In such case, the relative proportion of quartz in the mixed particle assigned 0.50 (4*12.5%). In the other case, as in Table 2, for the class between 85% < x ≤ 90%, 27 particles with the average proportion of 87.7% of quartz in the particle composition were counted. Thus, the mixed particles assigned 23.69% of quartz (27*87.7%).

Table 1 - Data table provided by the MLA after Mapping, Analyses, and Data Processing, for the Calculation of the Degree of Quartz Liberation. AGEO 1, ROM Desliming.

Quartz Composition of Particle (Wt%)	**Nº. of Particles**	**Quartz (%)**	Goethite (%)	Hematite/ Magnetite (%)	Mix Qz with Fe Oxides/ hydroxides (%)	**Mixed Particle Proportion by classes**	**Particle Types**
0%	**5952.0**	**0.0**	37.9	62.1	0.0	**0.00**	**Free oxide particle**
0% < x <= 5%	**48.0**	**0.1**	39.2	60.6	0.1	**0.06**	
5% < x <= 10%	**6.0**	**8.8**	16.9	73.8	0.5	**0.53**	
10% < x <= 15%	**4.0**	**12.5**	32.9	0.0	54.6	**0.50**	**Mixes Particle**
15% < x <= 20%	**6.0**	**17.5**	39.0	12.3	31.1	**1.05**	
20% < x <= 25%	**9.0**	**20.5**	26.1	53.4	0.0	**1.84**	
25% < x <= 30%	**5.0**	**26.7**	7.5	2.6	63.2	**1.33**	
30% < x <= 35%	**6.0**	**32.9**	6.0	0.0	61.1	**1.97**	
35% < x <= 40%	**5.0**	**38.4**	2.0	0.0	59.6	**1.92**	
40% < x <= 45%	**7.0**	**42.4**	31.7	25.7	0.2	**2.97**	
45% < x <= 50%	**7.0**	**47.6**	12.8	2.2	37.3	**3.33**	
50% < x <= 55%	**6.0**	**50.9**	20.7	28.1	0.3	**3.05**	
55% < x <= 60%	**5.0**	**56.3**	22.7	0.0	21.0	**2.82**	
60% < x <= 65%	**4.0**	**64.1**	35.9	0.0	0.0	**2.57**	
65% < x <= 70%	**4.0**	**68.1**	0.7	31.0	0.1	**2.73**	
70% < x <= 75%	**4.0**	**72.6**	14.4	0.0	13.0	**2.90**	
75% < x <= 80%	**7.0**	**75.9**	21.1	0.1	1.8	**5.31**	
80% < x <= 85%	**3.0**	**81.5**	0.0	18.3	0.2	**2.45**	
85% < x <= 90%	**1.0**	**87.1**	0.0	0.0	12.9	**0.87**	
90% < x <= 95%	**1.0**	**93.7**	1.5	4.7	0.1	**0.94**	**Free particle of quartz**
95% < x < 100%	**48.0**	**99.1**	0.6	0.2	0.0	**47.57**	
100%	**342.0**	**100.0**	0.0	0.0	0.0	**342.00**	

Table 2 - Data table presented by the MLA after the Mapping, Analyses and Data Processing, for the Calculation of the Degree of Quartz Liberation. AGEO 3, ROM desliming.

Quartz Composition of Particle (Wt%)	Nº. of Particles	Quartz (%)	Goethite (%)	Hematite/ Magnetite (%)	Mix Qz with Fe Oxides/ hydroxides (%)	Mixed Particle Proportion by classes	Particle Types
0%	**3119.0**	**0.0**	23.2	74.9	0.0		**Free oxide particle**
0% < x <= 5%	**130.0**	**1.4**	21.9	76.3	0.4	**1.82**	
5% < x <= 10%	**37.0**	**7.2**	23.2	68.8	0.7	**2.67**	
10% < x <= 15%	**25.0**	**12.6**	39.6	47.0	0.8	**3.15**	**Mixes Particle**
15% < x <= 20%	**15.0**	**16.4**	29.7	52.9	1.1	**2.45**	
20% < x <= 25%	**11.0**	**22.3**	29.9	46.8	0.9	**2.45**	
25% < x <= 30%	**15.0**	**28.3**	30.1	40.4	1.2	**4.24**	
30% < x <= 35%	**14.0**	**31.4**	36.5	30.1	2.0	**4.40**	
35% < x <= 40%	**16.0**	**37.0**	18.7	43.2	1.0	**5.93**	
40% < x <= 45%	**18.0**	**42.4**	19.5	36.8	1.2	**7.64**	
45% < x <= 50%	**11.0**	**48.8**	30.2	19.3	1.7	**5.37**	
50% < x <= 55%	**15.0**	**52.4**	19.5	27.5	0.5	**7.86**	
55% < x <= 60%	**17.0**	**57.7**	23.0	17.8	1.2	**9.81**	
60% < x <= 65%	**16.0**	**63.4**	14.4	21.5	0.5	**10.14**	
65% < x <= 70%	**19.0**	**66.7**	16.5	15.7	1.1	**12.67**	
70% < x <= 75%	**16.0**	**72.8**	10.2	16.1	0.7	**11.65**	
75% < x <= 80%	**20.0**	**77.5**	10.2	11.0	0.8	**15.51**	
80% < x <= 85%	**21.0**	**82.0**	8.2	9.2	0.6	**17.22**	
85% < x <= 90%	**27.0**	**87.7**	4.5	6.4	0.9	**23.69**	
90% < x <= 95%	**50.0**	**93.0**	4.6	1.5	0.6	**46.49**	**Free particle of quartz**
95% < x < 100%	**142.0**	**98.6**	0.7	0.3	0.1	**139.95**	
100%	**1130**	**100.0**	0.0	0.0	0.0	**1130.00**	

The degree of quartz liberation (L) is calculated by the general equation 1. For the first example, the liberation was calculated by equation 2, and for the second example, it was calculated by equation 3.

$$L = \frac{\sum \textit{Free particle of quartz}}{\sum \textit{Free particle of quartz} + \sum \textit{mixed particle}} * 100 \tag{1}$$

$$L = \frac{0.94 + 47.57 + 342.00}{\sum \textit{Free particle of quartz} + (\ 0.50 + 1.05 + 1.84 + \ldots + 0.87\ )} * 100 = \frac{390{,}51}{428.12} = 91.2\% \tag{2}$$

$$L = \frac{46.49 + 139.95 + 1103.00}{(\ 46.49 + 139.95 + 1103) + (\ 3.15\ldots + 15.51 + 17.22 + 23.69\ )} * 100 = \frac{1316.4}{1456.6} = 90.4\% \tag{3}$$

In doing so, the degree of quartz liberation, the aliquot of the flotation process according to the data obtained by optical microscopy and by the MLA to compare the results and to evaluate their influence in the process, was calculated for all the samples.

3. Results and discussion

3.1 Size analysis

Considering the mass % retained in the 9.4mm screen, which was established as a reference to compare the samples, the following results were achieved: AGEO 1: 22.5% (the finest one); AGEO 2: 84.6% (the coarsest one); AGEO 3: 56.1%; AGEO 4: 60.0%.

Intuitively, the particle size distribution can be correlated with the ore hardness, since coarse ores are harder than ores having fine granulometry (Ferreira 2013; Donda & Rosa 2014; Rodrigues 2016). Therefore, sample AGEO 2 is believed to be the hardest one, whereas sample AGEO 1 is the softest one; AGEO 3 and AGEO 4 samples presented intermediate results.

3.2 Chemical analysis

The Table 3 shows the chemical contents of ROM. It is observed that the sample AGEO 1 was the one with the highest Fe content and, consequently, the lowest SiO_2 content. The samples AGEO 2 and AGEO 3 had low Fe content, the latter with a high PPC content. The sample AGEO 4 had moderate Fe content and very low PPC content.

Table 3 – Chemical composition of the ROM.

Chemical Composition (%)						
ROM						
	Fe	SiO_2	Al_2O_3	P	MnO_2	LoI
AGEO 1	47,8	27,3	0,19	0,020	0,10	2,99
AGEO 2	34,8	48,1	0,04	0,013	0,02	2,00
AGEO 3	38,5	41,1	0,24	0,045	0,02	3,49
AGEO 4	40,5	39,9	0,12	0,030	0,10	0,81

3.3 Mineral composition

After the grinding process, the samples were deslimed and the underflow was submitted to mineralogical characterization by optical microscopy. The mineral composition is presented considering only the iron oxides and oxy-hydroxide in a modal composition, except for quartz or other gangue minerals.

The results are presented in Table 4 and Figure 3. According to the results, sample AGEO 1 presented goethite (44.0%), porous hematite (32.1%) and

Table 4 – Mineral composition of the ROM desliming sample observed in optical microscopy. SH: specular hematite; PH: porous hematite; G: goethite; MA: magnetite.

Mineral Composition (%)				
by optical microscopy				
	SH	PH	G	MA
AGEO 1	19.5	32.1	44.0	4.4
AGEO 2	2.7	41.1	44.3	11.9
AGEO 3	6.8	30.2	59.1	4.0
AGEO 4	51.6	28.2	15.0	5.2

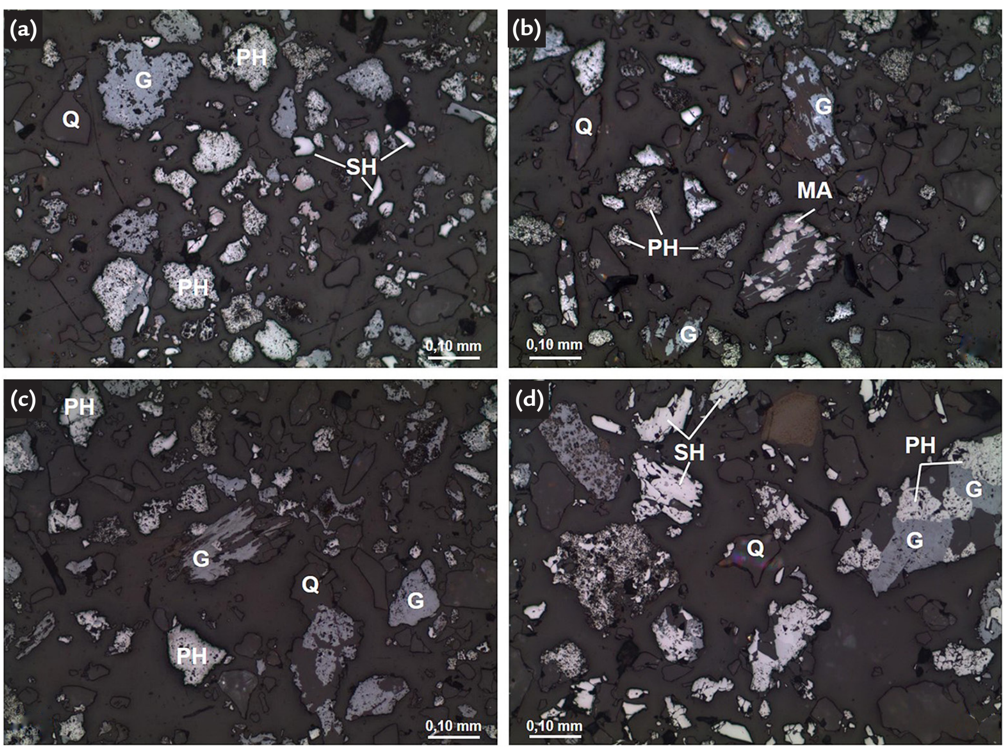

Figure 3 - Optical microscopy photos showing the general aspect of the ROM desliming samples. (a): AGEO 1; (b) AGEO 2; (c) AGEO 3 and (d) AGEO 4. SH – specular hematite; HP – porous hematite; G – goethite; Ma – magnetite; Q – quartz.

specular hematite (19.5%) as the main minerals in its composition. The samples AGEO 2 and AGEO 3 are mainly composed of goethite and porous hematite. AGEO 2 presented 44.3% of goethite and 41.1% of porous hematite whereas AGEO 3 is composed of 59.1% of goethite and 30.2% of porous hematite. In both cases, the sum of specular hematite and magnetite is slightly higher than 10%. Sample AGEO 4 is composed mainly of specular hematite (51.6%), followed by porous hematite (28.2%), goethite (15%) and magnetite (only 5.2%).

The mineral composition analysed by the MLA was not very different to that observed by optical microscopy. These data are presented in Table 5; they can be compared to the ones revealed by optical microscopy in Table 4. Figure 4 shows the micrographies with details of some ore particles, as also demonstrated by the scanning electron microscope employing backscattered electrons imaging (SEM-BSEI).

Table 5 - Mineral composition of the ROM desliming sample by MLA.

	Mineral composition (%) by MLA	
	Hematites + magnetite	Goethite
AGEO 1	53.9	46.1
AGEO 2	59.8	40.2
AGEO 3	50.2	49.8
AGEO 4	77.8	22.2

For the AGEO 1, the goethite content and the sum of the hematite and magnetite contents were similar in both techniques. In the MLA, the goethite was 46.1% and 44% in the optical microscopy while the hematite and magnetite presented 53.9% in the MLA and 56% by optical microscopy.

In the AGEO 2 sample, the goethite content was slightly higher in the optical microscopy (44.3%) than figures observed by the MLA (40.2%), and the hematite and magnetite contents were higher in the MLA, assigning 59.8% against 55.7%. For the AGEO 3, the situation was similar to AGEO 2's. The goethite content observed by optical microscopy was higher than the MLA results, with 59.1% and 49.8%, respectively. Consequently, the hematite and magnetite contents were also different, with 40.9% by optical microscopy and 50.2% by MLA.

The difference in the results presented by optical microscopy and MLA for the samples AGEO 2 and AGEO 3 can be explained by the size distribution and, obviously, by the differences in the techniques. First of all, these samples present coarser size distribution, therefore, the statistical representation may be affected in the analysis performed by optical microscopy, whereas the MLA works with a larger number of particles and more details. The hematite and magnetite present small grain size, as is seen in Figure 4. For this reason, in the MLA analysis, more hematite and magnetite grains are

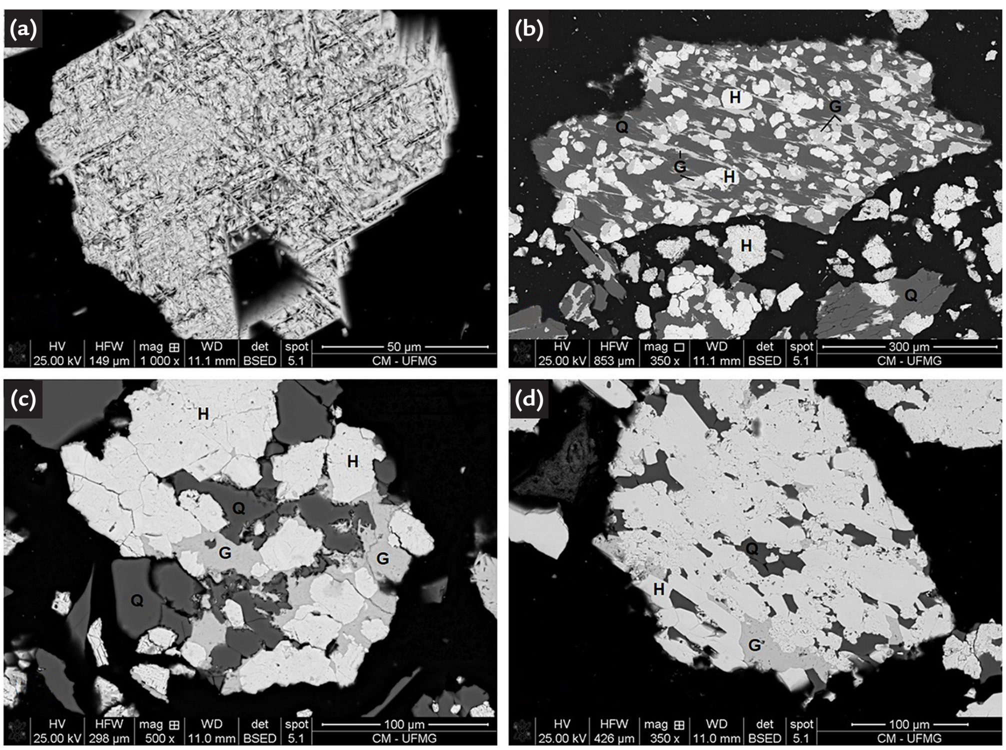

Figure 4 - Micrographies of the samples:
ROM desliming. SEM–BSEI. (a) - AGEO 1: detail of a porous hematite particle with a trellis texture.
(b) – AGEO 2: mixed particle of quartz (Q) with many hematite (H) and goethite (G) grains. (c) – AGEO 3: mixed particle composed of hematite (H), goethite (G) and quartz (Q). (d) – AGEO 4: mixed particle composed of hematite (H), goethite (G) and quartz (Q).

identified when compared to the analysis made by optical microscopy.

For the AGEO 4, the results also showed little difference between the techniques, with the goethite content of 22.2% in MLA and 15% in the optical microscopy whereas the hematite and magnetite presented 85% in MLA and 77.8% in the optical microscopy. The difference between the results probably occurred due to the higher specular hematite content with smaller grains rather than other minerals. Therefore, in MLA, it is possible to identify a larger number of specular hematite grains. Once again, the statistical representation may have been one of the reasons for the difference in results between the techniques applied, being the MLA a method able to count a large number of particles with great detailing in the phase segmentation in the particles (Fandrich 2007).

3.4 Mineral liberation

The mineral liberation hereby studied is based on the determination of the degree of quartz liberation. The results obtained by optical microscopy and those calculated according to the data verified by MLA are shown in Table 6.

Table 6 – The degree of liberation of quartz observed by optical microscopy (OM) and by MLA for the ROM desliming samples.

	Degree of Liberation of Quartz (%)		
	OM	MLA	Relative Error (%)
AGEO 1	90.5	91.2	-0.8
AGEO 2	78.6	74.1	6.1
AGEO 3	89.0	90.4	-1.5
AGEO 4	88.6	90.4	-2.0

Notice that the values of the quartz liberation degree determined by optical microscopy and by MLA were significantly close in all samples; the AGEO 2 presented the biggest difference between the values with a relative error of 6.1%. This sample corresponds to the ore with the smallest value of liberation degree, which could be accountable for this considerable difference. There is a large quantity of mixed particles with different proportions of quartz and iron oxide and oxy-hydroxide in this sample Thus, the counting of mixed particles can vary in the different techniques because of the method of analysis, considering the visual estimation in the optical microscopy. It is important to notice that the smaller the value of the liberation degree in the sample, the bigger is the difference between the techniques.

Regarding the results, the sample AGEO 1 corresponds to the thinnest ore, the ore with better value of degree of liberation of quartz – 90.5% by optical microscopy and 91.2% by MLA. In contrast, the AGEO 2 sample had the broadest size distribution and presented the smallest value of the quartz liberation degree, with 78.6% by optical microscopy and 74.1% by MLA. In the samples AGEO 3 and AGEO 4, the size distribution was similar and the values of the degree of liberation of quartz were also close. The AGEO 3 presented 89% and 90.4% of degree of liberation of quartz for optical microscopy and for MLA, respectively. In the AGEO 4, the degree of liberation of quartz obtained by the MLA was the same as that in the AGEO 3, and the value by optical microscopy was 88.6%.

For this reason, considering the values of the degree of liberation of quartz, the AGEO 1 is believed to present the best behaviour in the flotation process since it already has a low SiO_2 content. On the other hand, amongst all the samples studied, AGEO 2 is likely to present the worst result in the flotation process. The samples AGEO 3 and AGEO 4 may have a similar behaviour in the flotation process.

3.5 Concentration quality

The results obtained in the flotation process of the samples are shown in Table 7, with the chemical quality of the concentrate, the metallurgical recovery, mass recovery and iron content in the tailings.

Table 7 – Chemical Composition of the Concentrates.

	Chemical Composition (%)							Metallurgical Recovery (%)	Mass Recovery (%)
	Concentrate						Tailing		
	Fe	SiO_2	Al_2O_3	P	MnO_2	LoI	Fe		
AGEO 1	67.0	0.79	0.15	0.027	0.10	4.24	14.2	89.6%	61.8%
AGEO 2	57.7	14.0	0.06	0.021	0.03	3.17	25.1	44.6%	26.2%
AGEO 3	63.8	3.71	0.26	0.077	0.03	5.25	20.6	65.6%	39.5%
AGEO 4	66.8	3.35	0.19	0.059	0.10	1.72	30.0	43.7%	26.0%

The results obtained in the flotation process of the samples are shown in Table 7, with the chemical quality of the concentrate, the metallurgical recovery, mass recovery and iron content in the tailings.

The AGEO 1 sample showed the best performance in the flotation process among the samples studied, with the SiO_2 content in the concentrate of only 0.79% and the metallurgical recovery of 89.6%. On the other hand, AGEO 2 presented the worst result, with a SiO_2 content in the concentrate of 14% and a metallurgical recovery of only 44.6%.

The AGEO 3 and AGEO 4 samples showed similar levels of SiO_2 in the concentrate, 3.71% and 3.35%, respectively. However, the metallurgical recovery was discrepant with AGEO 3 showing a metallurgical recovery of 65.6% and AGEO 4 with 43.7%. The better metallurgical recovery of AGEO 3 in relation to AGEO 4 was a consequence of a better mass recovery and lower iron content in the tailings.

The liberation degree of quartz, despite being one of the basic prerequisites for the iron ore flotation process, is a variable that, alone, does not fully account for the behavior of the ore in the flotation process.

The ores of AGEO 1, AGEO 3 and AGEO 4 showed similar values for the liberation degree of quartz, respectively 91.2%, 90.4% and 90.4% via MLA, and totally different flotation performances, mainly when comparing the AGEO 1 sample with the AGEO samples 3 and 4. Therefore, this result indicates that there is a need for further studies addressing the different types of free and mixed particles, the distribution of particle types, and the mineralogical composition of these particles, so that a better understanding of the process and the prediction of the ore behavior in the flotation process could be achieved (Rodrigues 2016).

4. Conclusion

Considering all the results, it is possible to state that the degree of liberation of quartz is a relevant variable in the prediction of the ore behaviour in the flotation process. Nevertheless, a complementary study is necessary so that what happens in the flotation process can be fully understood. The analysis considering the different types of free and mixed particles, the percentage distribution of these particles, the mineralogical composition of each particle type, are some of the information obtained in the mineralogy characterization.

Both techniques, optical microscopy and MLA, offered very similar results for the degree of liberation of quartz. Each technique presents advantages and disadvantages, but they complement each other, with the MLA offering great detailing and great statistical representation in the analysis while the optical microscopy enables a more interpretative analysis.

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