Bauxite XRD cluster for the prediction of mineral processing behaviors

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Abstract

X-ray diffraction (XRD) cluster analysis in support of mineral exploration and mining operations has been highlighted in recent ore characterization and geometallurgical studies. This tool enables the definition of geological domains or ore types with distinct mineralogical compositions and their potential implications in mineral exploration and/or processing behavior without the need for deeper XRD expertise.

The simultaneous analysis of a large number of scans by mineralogical similarity reduces the number of data to be treated once it is possible to select the most representative scan from each cluster for further analyses. The blending of a large set of samples also minimizes the number of mineralogical, metallurgical and minerals separation assays, reducing time and costs of the ore evaluation.

In this study, 69 bauxite samples from Porto Trombetas, Brazil, were classified by cluster analysis. Results led to six groups and their subgroups, which correspond to the different geological weathering horizons of bauxite formation, each with different gibbsite, clay mineral and iron bearing mineral content.

Scrubbing, size classification and mineral separations were conducted for each sample. The results demonstrated that samples from the same cluster present similar chemical and mineralogical compositions as well as an equivalent behavior on the mineral separation assays.

Keywords: X-ray diffraction, cluster analysis, bauxites, geometallurgy.

1. Introduction

X-ray diffraction (XRD) cluster analysis can be used to provide valuable information for mining and process control in the mining industry through a fast statistical evaluation that puts the XRD patterns into classes or clusters defined by their similarities [1,2]. The simultaneous analysis of large numbers of XRD scans by similarity reduces the amount of data to be analyzed since it is possible to select the most representative scan from each cluster for further interpretation.

This statistical method simplifies the analysis of large number of data by automatically selecting the most representative scan of each cluster and also the scans that most differ. It can also be used as a starting point for more detailed investigations. This assists sample processing, for example from drill core sampling, and allows a multi-dimensional compositional mapping of ore deposits that identifies mineralogical variability and allows fast and reliable quality control tracking in the minerals and mining industries [3]. The blending of a large sample set based on XRD cluster analysis also minimizes the number of mineralogical, metallurgical and minerals separation assays, reducing time and costs for ore evaluation.

Brazilian sedimentary bauxite deposits have a significant compositional variability; they are originally related to the remobilization and redistribution of chemical elements by the laterization process. The bauxite mineralized zone reveals vertical profile layers from top to bottom, such as nodular bauxite, laterite lithofacies and massive bauxite, each containing differing gibbsite, clay mineral (kaolinite group) and iron oxy-hydroxides contents [4]. Traditionally, the massive bauxite horizons receive economic interest due to their high proportion of gibbsite [$Al(OH)_3$] and lower clay minerals content.

The cluster analysis applied to high variable materials becomes more attractive if it reflects distinct behavior in mineral processing in addition to distinguishing samples based on their mineralogical composition. This study compares the results of cluster analysis with processing mineralogy data from 69 bauxite samples and evaluates the effectiveness of this approach in forecasting ore behavior as a geometallurgical tool.

2. Experimental

2.1. General

The studies were performed on 69 bauxite samples from Mineração Rio do Norte (MRN) in the Porto Trombetas region in the state of Pará, Brazil. The samples were classified on the mining site according to their lithology as: nodular (30), laterite (25) and massive bauxite (14).
The experimental procedure is shown in Figure 1.

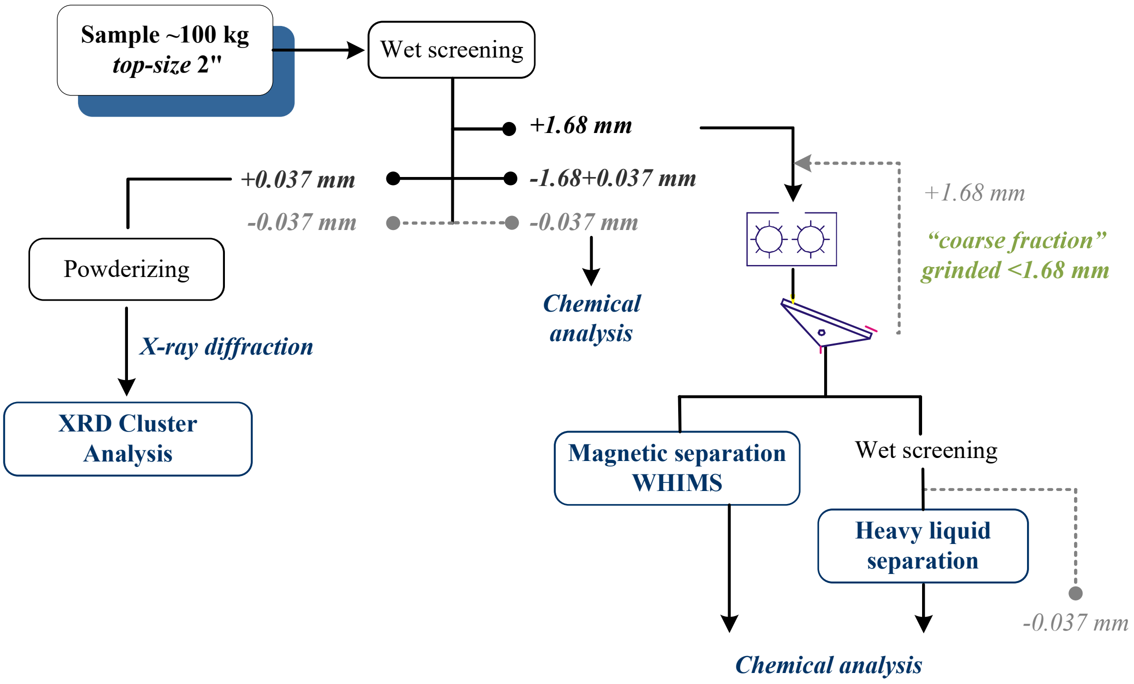


Figure 1 - Laboratory procedure

Volumetric samples collected were first crushed to minus 2" (50 mm) and then 100 kgs were split for the current studies. The samples were initially scrubbed and submitted to wet sieving. The sieve fractions above 0.037 mm were selected for XRD diffraction analysis and the fractions above 1.68 mm for process mineralogical studies.

2.2. XRD cluster analysis

The powder XRD analysis was conducted using a PANalytical X'Pert Pro diffractometer with a Cu kα radiation, 45kV/40mA, 2θ ranging from 5 to 70º, 0.02º 2θ step size, X'Celerator PSD detector with 10s time/step and fixed incident & divergent slits. The sample preparation consisted of powdersizing in a planetary ball mill below 0.04 mm and manual back loading pressed in a proper sample holder.
XRD cluster analysis was accomplished using High Score Plus software tools that allow sample classification by hierarchal correlation of similar mineral compositions. The adopted analysis

conditions were profile + peaks data source, position + intensity FOM type, 50% compare threshold, Euclidian distance measure, Average Linkage method and manual limitations groups (cut-off).

2.3. Process mineralogy studies

The process mineralogy studies were conducted on the 69 samples at fractions from wet sieving. The fractions above 1.68 mm, which represent 53 to 68% of the weight, were grinded below 1.68 mm (d100) and then submitted to wet high magnetic intensity separations (WHIMS) with 5 mm Jones matrixes at 7 kG (open field), and to heavy liquid mineral separation for the fractions above 0.037 mm (bromoform $d=2.8\ g/cm^3$).

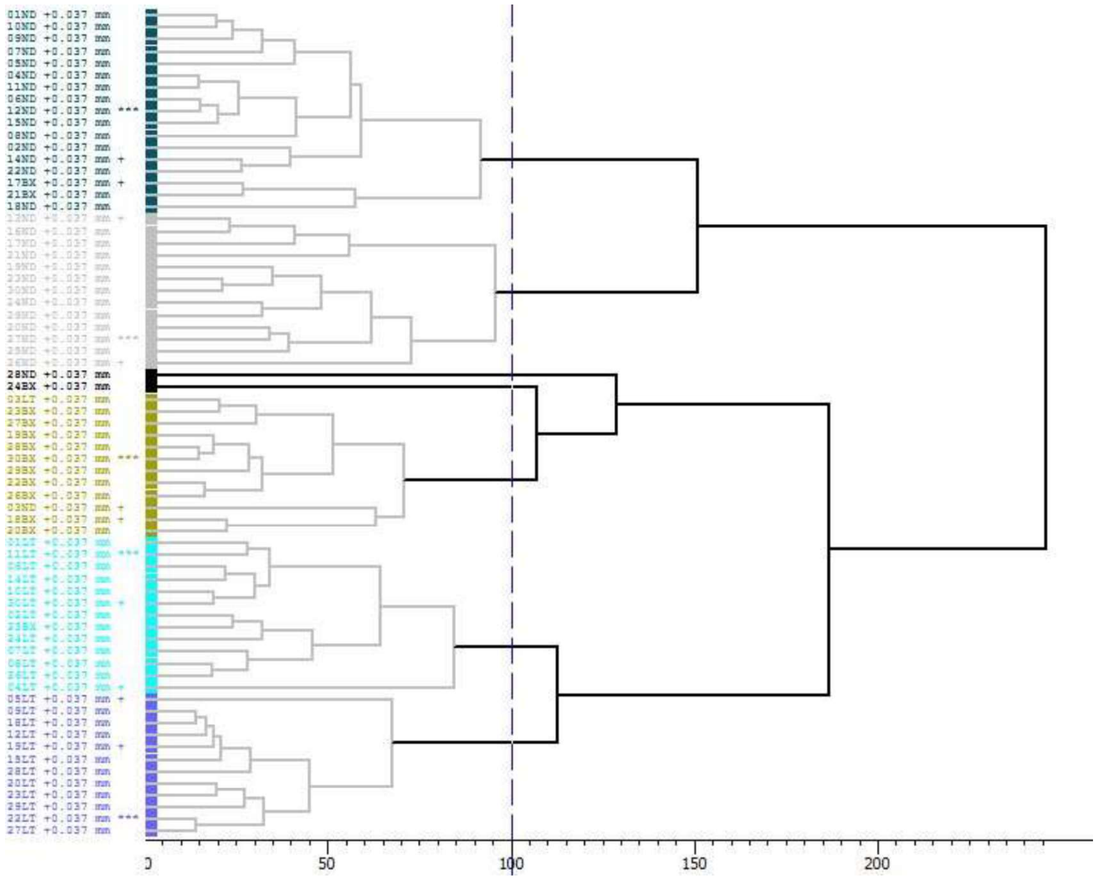
Chemical analysis for the extractable alumina and reactive silica grades were attained by selective dissolution (MRN Laboratory) and the Fe_2O_3 oxide was determined by X-ray fluorescence (PANalytical Axios at the Technological Characterization Laboratory at the University of Sao Paulo).

3. Results

3.1. XRD cluster analysis

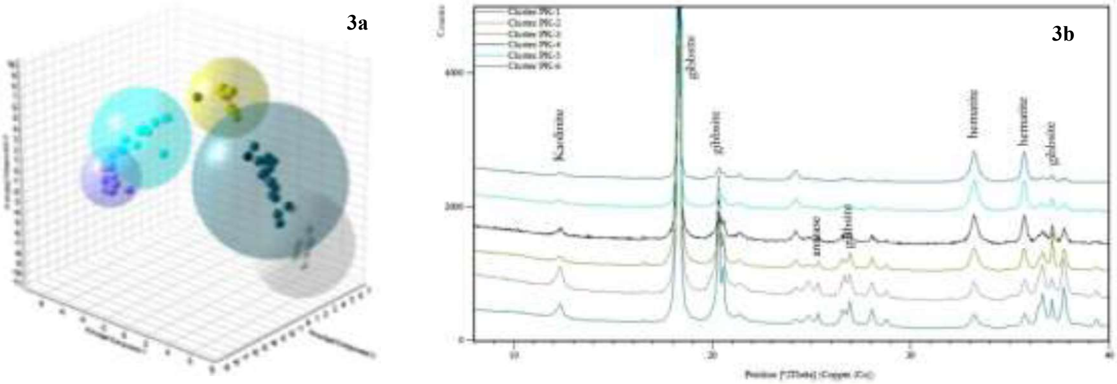
The clustering results for the studied samples (fractions >0.037 mm) allowed six distinct mineralogical groups to be identified, named PK-1 to PK-6, as illustrated by dendogram (Figure 2) and Principal Component Analytic diagram (PCA) using a 3D-graphic of the three initial Eingelvalues (Figure 3a - PCA1 to PCA3). The samples included in each group are listed and similarities and dissimilarities between them are noted.

The mineral composition observed in the studied samples is basically gibbsite $[Al(OH)_3]$ and kaolinite $[Al_2Si_2O_5(OH)_4]$, with minor amounts of hematite (Fe_2O_3), anatase (TiO_2) and quartz (SiO_2). Figure 3b shows the comparison between the average XRD scans from each group, enabling visualization of the highlighted mineralogical differences and consideration of the main constituents and their relative proportions.



Samples marked with *** are the most representative of each group, and marked with the + sign are the most different. Green = cluster PK-1; Grey = cluster PK-2; Yellow = cluster PK-3; Black = cluster PK-4; Cyan = cluster PK-5; Blue = cluster PK-6).

Figure 2 - Dendogram for the 69 clustering analysis samples, manual cut-off



Green = cluster PK-1; Grey = cluster PK-2; Yellow = cluster PK-3; Black = cluster PK-4; Cyan = cluster PK-5; Blue = cluster PK-6.

Figure 3 – 3D spatial distribution of Principal Component Analysis (PCA1 to PCA3) related to the samples groups (3a) and comparison between the XRD average patterns of each cluster (3b)

The nodular samples (clusters PK-1 and PK-2) present the highest content of clay minerals (kaolinite), while the lateritic samples (clusters PK-5 and PK-6) show significant levels of iron minerals (hematite & goethite). The PK-3 features those samples with high grades of gibbsite (massive samples) and the PK-4 presents intermediate levels between nodular and massive lithofacies.

The PK-1cluster is preferentially composed of nodular bauxite (15 nodular and 2 massive), while the PK-2 is composed only of nodular bauxite samples (13 in total), with a subtle increase in reactive silica content. The PK-3 contains preferentially massive samples (10 massive, 1 nodular, 1 laterite) and the cluster PK-4 is an outlier group containing only two different samples (1 nodular and 1 massive) with higher goethite-hematite content.

The PK-5 and PK-6 clusters are represented by lateritic ore with higher iron content in the latter (35% Fe_2O_3 on average).

3.2. Process mineralogy studies

Process mineralogy studies were performed for each sample from the defined groups. The grades of extractable alumina, reactive silica and total iron in the head samples, the fractions above 1.68 mm, and the non-magnetic and float products from mineral separations are shown in Figure 4. It is possible to distinguish the average value for each cluster and the range of values between samples arranged in a defined group.

The fraction above 1.68 mm presents a significant increment in extractable alumina grades and reduced content of reactive silica due to the removal of clay minerals; iron grades are similar to the head sample. Non magnetic products present reduced Fe_2O_3 grades, and the float products from heavy liquids present even greater Fe_2O_3 reduction; reactive silica grades show a subtle non magnetic reduction and a greater reduction for float products. As previously presented [5], density separation is more selective than magnetic separation in achieving higher extractable alumina grades and lower iron and reactive silica content.

Figure 5 illustrates the weight, extractable alumina, reactive silica and iron oxide recoveries in the studied samples. Head sample grades are noticeably distinct between XRD clusters, although these grade distinctions reduce with sample processing – sizing, magnetic separation and heavy liquid separation (Figure 4). They increase in terms of weight, extractable alumina, reactive silica and iron recoveries (Table 1 and Figure 5).

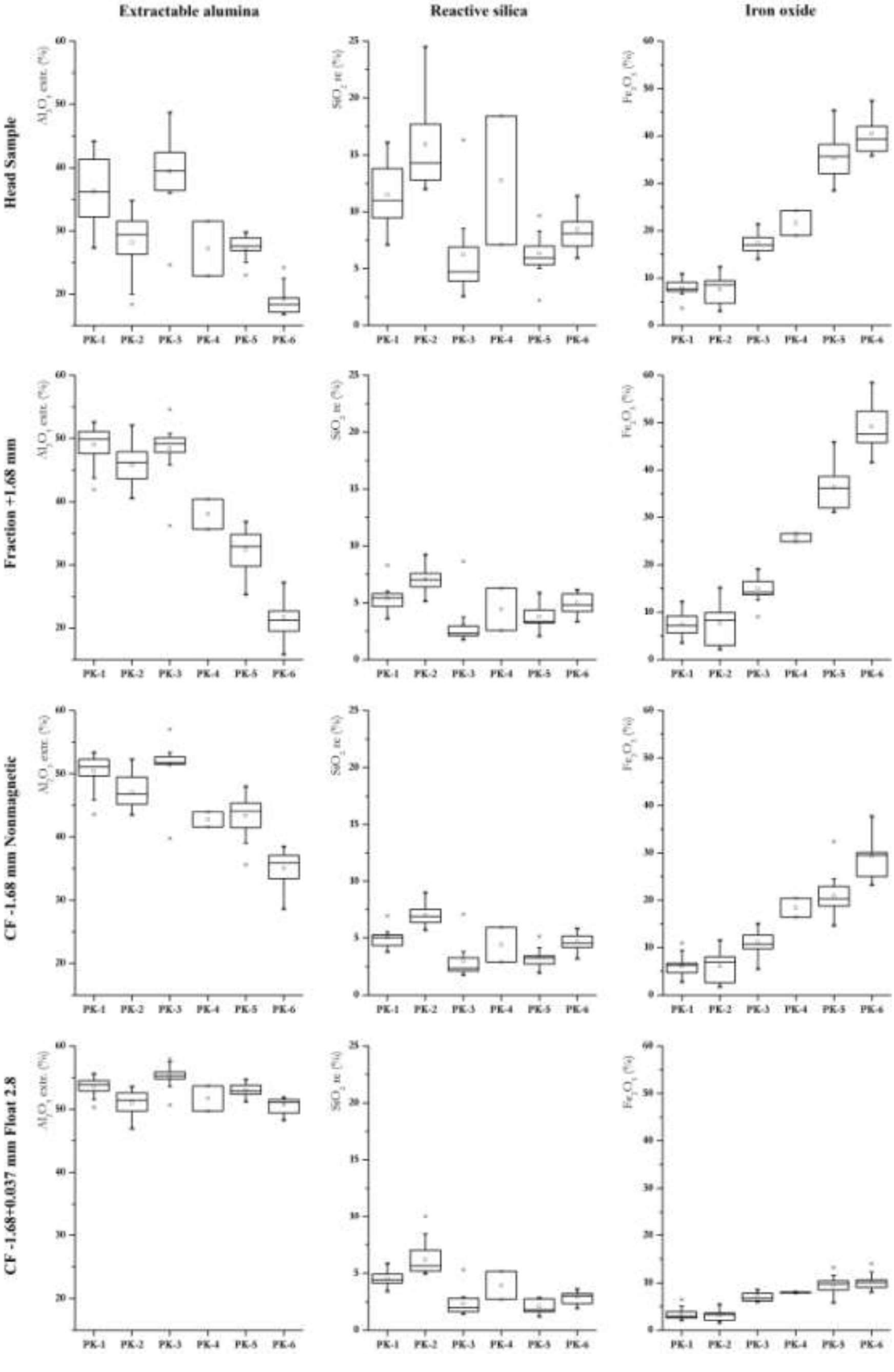


Figure 4 – Grades of extractable alumina, reactive silica and iron oxide for studied samples classified according to XRD clusters

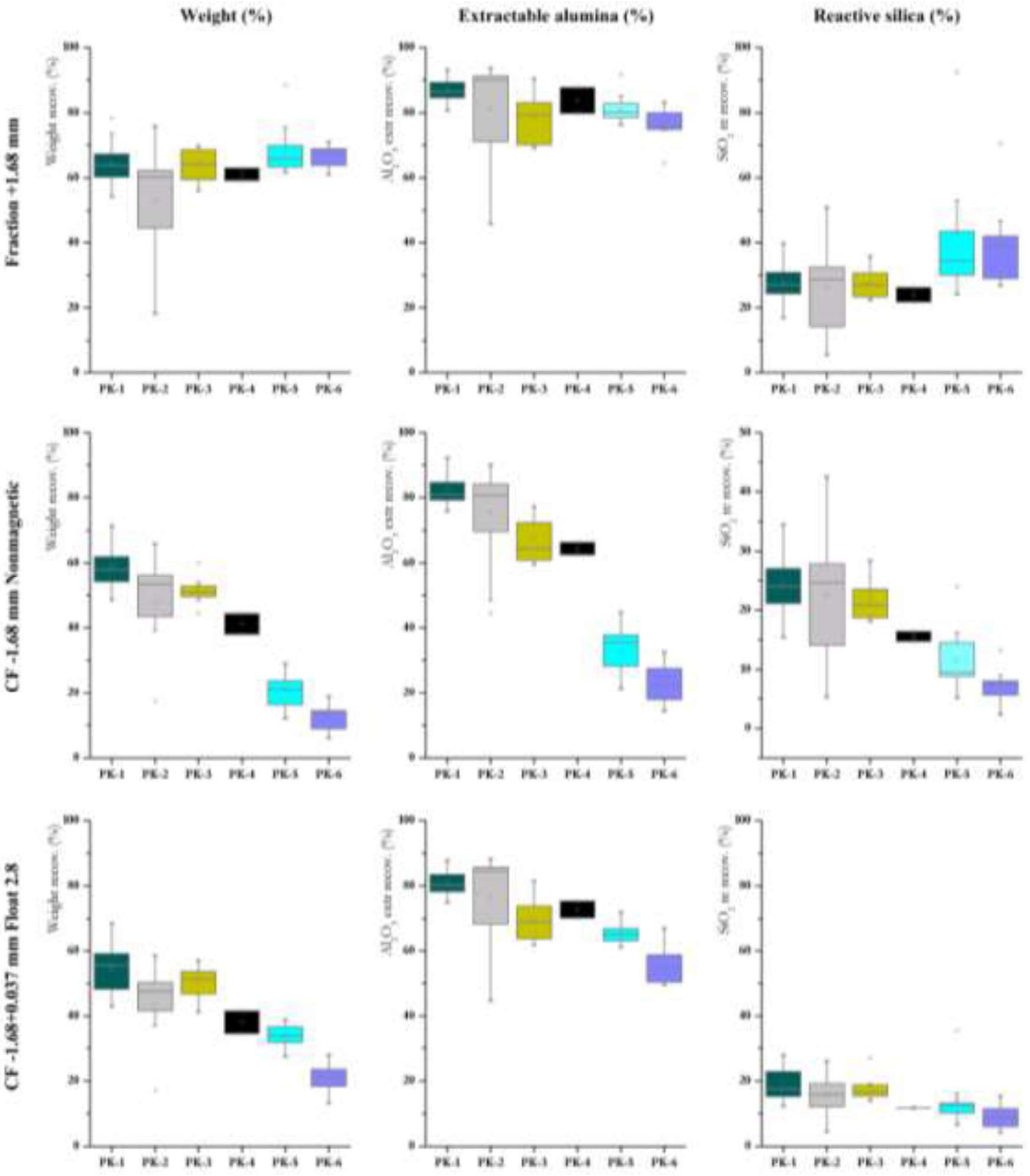


Figure 5 – Recoveries from weight, extractable alumina and reactive silica for studied samples classified according to XRD clusters

Table 1 - Results of process mineralogy studies - grain size analysis and mineral separations

Fraction / Product	*Cluster*	*Average results for XRD clusters*						
		%	*Grades (%)*			*Distribution (%)*		
		weight	$Al_2O_{3\ extr}$	$SiO_{2\ re}$	Fe_2O_3	$Al_2O_{3\ extr}$	$SiO_{2\ re}$	Fe_2O_3
Head samples	PK-1	100.0	36.3	11.5	7.9	100.0	100.0	100.0
	PK-2	100.0	28.2	15.9	7.6	100.0	100.0	100.0
	PK-3	100.0	39.4	6.2	17.4	100.0	100.0	100.0
	PK-4	100.0	27.2	12.8	21.6	100.0	100.0	100.0
	PK-5	100.0	27.3	6.3	35.3	100.0	100.0	100.0
	PK-6	100.0	19.2	8.5	40.5	100.0	100.0	100.0
+1.68 mm	PK-1	64.3	49.0	5.4	7.4	87.2	27.7	62.3
	PK-2	53.0	45.8	7.1	7.6	81.1	26.3	51.1
	PK-3	64.3	48.4	3.0	15.0	78.3	27.8	56.3
	PK-4	61.1	38.0	4.4	25.8	83.8	24.1	69.0
	PK-5	68.2	32.5	3.8	36.3	81.0	42.5	71.2
	PK-6	66.6	21.7	5.0	49.2	76.7	39.7	76.9
CF -1.68 mm Non-magnetic	PK-1	59.1	50.4	5.0	6.1	82.3	24.5	46.0
	PK-2	47.5	47.1	7.0	6.1	75.6	22.5	37.2
	PK-3	52.0	51.4	3.0	11.1	67.1	21.8	33.8
	PK-4	41.2	42.8	4.4	18.4	64.4	15.6	33.1
	PK-5	20.9	43.4	3.3	20.9	33.2	11.6	12.8
	PK-6	12.9	35.1	4.6	29.3	23.4	7.6	9.0
CF -1.68+0.037 Float	PK-1	54.4	53.6	4.5	3.5	80.9	19.1	23.2
	PK-2	43.4	51.0	6.2	3.2	76.4	15.8	16.8
	PK-3	50.2	55.3	2.4	7.1	69.9	18.2	19.9
	PK-4	38.1	51.7	4.0	8.0	72.7	11.7	12.3
	PK-5	33.8	53.0	2.1	9.5	65.2	14.4	9.3
	PK-6	21.3	50.7	2.9	10.3	56.4	9.6	5.1

Notes: CF = "coarse fraction" grinded; Al_2O_3 extr = extractable alumina; SiO_2 re = reactive silica.

The PK-1 and PK-2 cluster samples (nodular lithofacies) have similar proportions of analyzed oxides, but the first presents lower reactive SiO_2 content (11.5 versus 15.9%) and a higher proportion of extractable Al_2O_3 (28.2 versus 36.3%).

For the above 1.68 mm fraction, the reactive SiO_2 content is significantly reduced in both groups (5.4% in PK-1 and 7.1% in PK-2). Considering only the non-magnetic product of the grinded sample (<1.68 mm), the recoveries of extractable Al_2O_3 are 82.3% in the PK-1 and 75.6% in the PK-2, the remaining levels of reactive silica are 5-7% and there is lower Fe_2O_3 content (6.1% in both groups). The heavy liquid float product also removes deleterious reactive SiO_2 content, reaching 4.5% in the PK-1 and 6.2% in the PK-2; the Fe_2O_3 contents are also reduced to between 3.2-3.5%.

The PK-3 cluster (massive bauxite horizon) head samples correspond to the highest levels of extractable Al_2O_3 (39.4%), reaching 55.3% in float product from heavy liquid separation, with 2.4% of reactive SiO_2 and 7.1% of Fe_2O_3 associated.

The samples from PK-4 (the small outlier group) present considerable levels of reactive SiO_2 (12.8%) and Fe_2O_3 (21.6%), which decrease noticeably in the float product, presenting 4.0% of reactive SiO_2, 8.0% of Fe_2O_3 and 51.7% of extractable Al_2O_3.

PK-5 and PK-6 cluster head samples (laterite horizon) also show similar proportions of the analyzed oxides, but the PK-6 presents higher Fe_2O_3 content (40.5 compared to 35.3%) and reactive SiO_2 content (8.5 compared to 6.3%), and a smaller proportion of extractable Al_2O_3 (19.2 compared to 27.3%).

For the above 1.68 mm products, the grades of reactive SiO_2 are significantly smaller (5.0% in the PK-6 and 3.8% in the PK-5). The magnetic separation promotes significant reductions in Fe_2O_3 grades for the non-magnetic products (20.9% in PK-5 and 29.3 in PK-6). As well, associated extractable alumina levels surpass 35% and weight recoveries are relatively low (13% and 21%). Float products from heavy liquids allow a greater reduction in Fe_2O_3 grades (9.5-10.3%) associated with more than 50% of extractable alumina, 2.1-2.9% of reactive SiO_2 and weight recoveries of only 21% to 34%.

4. Conclusions

Cluster analysis of X-ray diffraction patterns allowed easy and fast bauxite ore discrimination based on the major minerals content – gibbsite, kaolinite and hematite-goethite.

The data attained from traditional mineralogical processing tools applied to bauxite ore characterization, such as wet sieving and magnetic and heavy liquids mineral separations, showed a very strict and consistent relation to the XRD clustering groups.

Six distinct groups of samples with similar mineralogical composition were established. The two lateritic ore groups allowed the generation of products with very similar characteristics to massive bauxite despite the observed lower weight recoveries. It is noted that these ores are not currently exploited. Cluster analysis of XRD scans through fast statistical evaluation of large sets provides valuable ore classification information based on mineralogical composition. For the characterized ore samples, the cluster analysis reflects the process mineralogy and mineral processing performance in terms of both product grades and recoveries and, consequently, their geometallurgical behavior.

5. References

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6. Acknowledgementes

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