

CHARACTERIZATION OF THE RARE EARTHS ORE DEPOSIT FROM CORREGO DO GARIMPO, GO, BRAZIL

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ABSTRACT

The Catalão alkaline complex presents two rare earths mineral deposits, both related to monazite as the major rare earths elements (REE) bearing mineral. The first and larger one, Corrego do Garimpo, is described as a lateritic material derived from hydrothermal alteration from dolomitic carbonatitic rocks; the other deposit, recently discovered, is related to the remobilization and further sedimentation in a hydrothermal environment.

Although the deposit of Corrego do Garimpo is known since the sixties, all the previous mineral dressing attempts made for the concentration of the REE bearing minerals resulted in unsatisfactory outcomes. Process mineralogy studies of bulk and borehole samples were fundamental to the understanding of the ore's behaviour and to the development of an unusual physical concentration process. The ore comprises a medium to very fine-grained soil horizon with large amounts of secondary minerals, including silicified material. Monazite occurs as microcrystalline aggregates, sometimes presenting colloidal texture, which is frequently associated with iron oxide-hydroxides and quartz. Since these aggregates are extremely friable, the monazite crystallites are mainly associated with the size fractions below 20 µm. These particular characteristics supported the development of an unconventional mineral processing method based on desegregation, followed by scrubbing and hydrocyclone classification operations. Three volumetric samples and 29 borehole samples, comprising the four defined ore types, had been studied. The attained final products, <10 µm, presented 30% in weight in average with a grade of 19,5% REO and recoveries from 60 to 70% of the REE. Individual sulfuric acid leaching tests of these products, simulating a chemical processing for the REE extraction at low temperature, showed an average global recovery in the order of the 30-50% of the initial REE content in the ore samples.

INTRODUCTION

There are numerous occurrences of REE deposits and important resources associated with Brazilian alkaline-carbonatitic complexes. REE bearing minerals may occur as the main valuable component in well-individualized deposits as well as potential by-products derived from other minerals, such as apatite. Although thus resources are significant, a satisfactory technological solution for their economic use is still missing (Tassinari et al, 1998).

The Catalao-I ultramafic alkaline-carbonatitic complex is situated in the SE of Estado de Goias. It presents important apatite, Ba-pyrochlore, anatase, REE and vermiculite mineralizations. The first two minerals are being exploited for almost 20 years in four open pit mines.

The Corrego do Garimpo REE deposit is located in the south border of the *Area 1* open-pit from the Ultrafertil phosphate mine. It presents some overlay with the phosphate mine pit, reason enough to urge a technological solution, otherwise some REE resources would be lost. The potential REE resources comprises 17.7 Mt with an average grade of 7.6% REO (REE oxides) at 5% REO cut-off grade (1.12 Mt of REO). Other important characteristic is the very low grade of U and Th in this deposit.

A great number of previous mineral dressing works were reported, all of them accomplished considering several concentration processes. However, no satisfactory results were achieved due to the very fine crystallite sizes of the valuable minerals (Vieira et al, 1998; Neumann, 1999; Barros & Rosenthal, 1999). The obtained recoveries of REE were usually below 30% with REO grade rarely reaching 20%. Direct hydrometallurgical studies of both crushed and finely ground were also economically unfeasible.

Initial detailed applied mineralogical studies were performed with a sample from the saprolitic material collected in the phosphate open pit mine. The goal of

these studies were to determine the mineralogical compositions and associations as well as to reevaluate the mineral concentration potential through physical processes, aiming at generated a pre-concentrate of REE minerals for subsequent hydrometallurgical treatment. Later on, a systematical and comparative study was extended to the entire ore body considering borehole and other volumetric samples.

METHODOLOGY

The study of the saprolitic sample comprised its comminution below minus 0.84mm, followed by 10 minutes scrubbing operation and wet screening into seven size fractions. Each size fraction was submitted to mineral separation with heavy liquids, di-iodo-methane (S.G. 3.32), and Frantz mineral separator. All the products that were obtained by mineral separation were submitted to chemical and detailed mineralogical analyses. Chemical analyses were accomplished by X-ray fluorescence and the mineralogical analyses by integration of optical microscopy, X-ray diffraction (XRD) and scanning electron microscopy (SEM) coupled to an energy dispersive spectrometer (EDS), respectively, Philips PW-2440 spectrometer, Philips PW-1710 diffractometer, Leo S440 SEM and Oxford Isis 300 EDS.

An alternative and unusual mineral dressing process was indicated by the results of the applied mineralogical work (Tassinari et al, 1998). Then mineral processing studies in bench scale were performed in order to evaluate and optimize the proposed process. This study was based on a sample from the phosphate face mining, and a routine laboratory procedure was established.

Later on, a standard test procedure established and applied for the entirely REE deposit, with the objective of verifying the applicability of the developed process for the different ore types recognized in the mineral deposit, as well as to generate material for further hydrometallurgical tests. This standard test procedure was performed on two other volumetric samples and 27 composed borehole samples spread along the Corrego do Garimpo ore body.

RESULTS

Mineralogical studies on the saprolitic sample

The saprolitic ore sample presented 8.4% REO and 28.4% Fe₂O₃, 15.8% SiO₂, 9.1% CaO and 9.0% TiO₂ as the major oxides. The distribution of these major oxides in the sample ground below 0.84mm is presented in the Figure 1.

The distribution of the major oxides clearly shows the strong tendency of the REO to concentrate in the fine size fractions; similar behavior, although less emphasized, is presented by the Fe₂O₃. The other major oxides SiO₂ and TiO₂, as well as CaO and Al₂O₃, are enriched in the coarse size fractions. Thus, just applying a scrubbing and screening classification, the coarse size fraction above 0.3 mm showed a grade of 3% REO, while the finest one, below 0.02 mm, presents 23% in weight and a grade of 20% REO and 36% Fe₂O₃, recovering more than 50% of the total REO content.

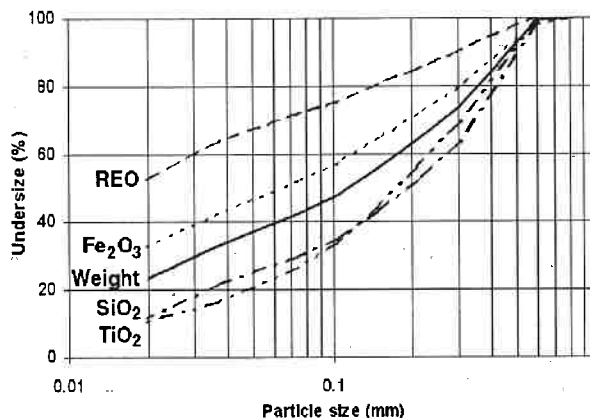


Figure 1. Weight and oxides distributions by size fraction

The summary of the mineral separation results accomplished in the coarse size fractions, above 0.02 mm, is presented in Table I.

Table I - Results of mineral separation (-084 +0.02mm)

Product	Wt %	Grades (wt %)					REO rec.%
		REO	Fe ₂ O ₃	SiO ₂	CaO	P ₂ O ₅	
float .3.3	31,4	1,7	7,8	39,8	13,0	11,9	6,5
sk +1.5 kG	19,2	2,4	57,1	2,8	4,4	6,1	5,4
sk +3 kG	12,9	8,4	35,9	2,4	6,9	10,9	12,8
sk -3 kG	13,2	13,7	15,3	2,3	16,1	19,8	21,5
total	76,7	5,1	26,1	17,8	10,4	11,6	46,3

sk - sink product at S.G.3.3; magnetic field in kGauss

The float product on S.G. 3.3 is constituted essentially by SiO₂, CaO, P₂O₅, Al₂O₃ (5.0%) and MgO (6.6%), which are basically associated to quartz, apatite and clay minerals presence. In the magnetic separation of the sink products, the REE are mainly associated with the non magnetics at 3 kG, with grades between 12.5 and 15.7% of REO for the different size fractions; besides REO, the main oxides present in this product refer to P₂O₅, CaO, Fe₂O₃ and TiO₂. The magnetic product at 1.5 kG is essentially constituted by Fe₂O₃ and

TiO₂ related to magnetite, goethite and ilmenite. The intermediate product, magnetic at 3 kG, is still showing very high content of Fe₂O₃ in addition to substantial amounts of TiO₂, REO, P₂O₅ and CaO.

The saprolitic sample is essentially composed by iron oxides/hydroxides (predominantly goethite, besides of magnetite and hematite) - 24%, clay minerals (chlorite, vermiculite and hydromicas - 12 Å) - 18%, apatite - 16%, monazite - 13%, quartz - 10%, and ilmenite - 8%; the accessory minerals are represented by anatase, secondary aluminum phosphate (gorceixite), barite and zirconium minerals. Monazite-rhabdophane [(Ce, La)PO₄ - (Ce, La)PO₄.H₂O] are the main REE bearing minerals, other REE minerals are very rare.

SEM work was fundamental to determine and to understand the ore textures due to the extremely fine grain size of the major mineral phases (Tassinari et al, 1999). Monazite-rhabdophane usually occurs as microcrystalline aggregates, sometimes presenting colloform textures, associated with iron oxide/hydroxides, apatite and quartz (Figures 2a, b, c). Crystallites sizes are up to a few microns in diameter and show backscattered contrast variations, probably related to the amount of water in the monazite-rhabdophane structure. These remarkably friable aggregates provide monazite-rhabdophane with the strong and natural tendency to break up and, consequently, to concentrate in the finest size fraction.

Ore processing development

The remarkable breaking up characteristic of monazite-rhabdophane indicates the possibility of their concentration supported by this particular and unusual characteristic. A mineral processing method considering breaking up by successive scrubbing and hydrocyclone classification cycles was performed in order to drive the largest possible amount of REE to the slime fraction (<10 µm). This process generated an ultrafine concentrate, a coarse tailing and an intermediate fine product to be further processed by conventional operations, such as flotation, or equally be also rejected as a tailing product.

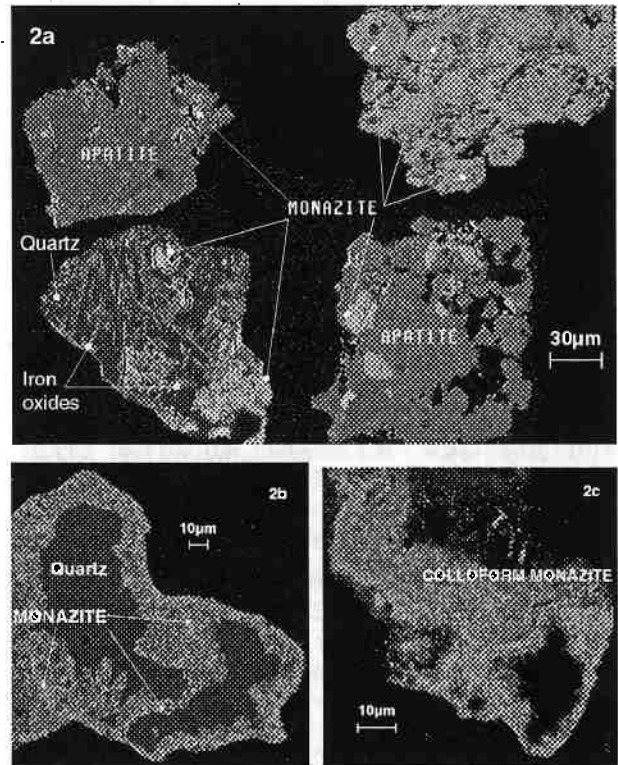


Figure 2. Monazite textures: 2a presents general monazite associations; 2b shows a very fine intergrowth with quartz and 2c a very fine colloform texture.

Different grinding conditions coupled with hydrocyclone classification and scrubbing operations cycles were evaluated products. The metallurgical balance results of these tests showed that the best alternative is the one without grinding the material, being just constituted by classification and scrubbing stages with selective monazite breaking up. As shown in Table II, it was possible to attain products with an amount of 18.5% REO and recoveries in the order of 70%. Only Scrubbing and classification, without any grinding operation, achieved a grade of 21% REO and 76% REO recovery.

The characteristics of this final concentrate for the saprolitic ore are presented in Table III. It is essentially constituted by monazite, goethite and clay minerals.

Wet magnetic separations were carried out with the objective of reducing the amount of iron, which is associated with this concentrate. However, it didn't succeed because its highly flocculated condition.

Table II. Results of mineral dressing tests

Sample preparation		Final products		
Size (mm)	Scrubbing	Weight %	REO %	REO recov. %
- 12.5	10 min	32.0	20.8	76.0
- 0.84	10 min	30.3	18.5	69.9
- 0.42	not applied	29.4	18.4	70.9

Table III. Characteristics of the final concentrate

Wt. %	Grades (wt. %)						REO recov. %
	REO	Fe ₂ O ₃	SiO ₂	TiO ₂	CaO	P ₂ O ₅	
31.0	20.9	34.9	9.3	3.6	4.0	11.4	77.2

Ore deposit characterization

After defining one beneficiation process for the REE concentration, the entire REE ore deposit the needed to be evaluated. Three other volumetric samples were processed and, later on, 27 borehole samples.

The volumetric samples generated final concentrates with weigh recoveries between 17.5 and 19.2%, REO grades from 10.2% to 21.9% and REO recoveries from 39% to 62%.

A preliminary ore type classification was based on log descriptions and chemical analyses of drill cores. The main distinctive aspects were related to the grades of SiO₂, Fe₂O₃, CaO (indicative of the apatite presence) and MgO (indicative of the carbonate presence - fresh rock). Four preliminary weathered ore types would be defined based on these criteria; their distribution in the deposit, grades and REO partition are shown on Table IV. The *silexite ore* corresponds to a compact and coarse silicified material; the *highly iron ore* refers to the friable and very fine material with high content of iron oxide/hydroxides, mainly represented by goethite. The *intermediate ore* corresponds to a miscellaneous situation between *silexite* and *highly iron ore* types. A friable material with substantial amount of apatite characterizes the final one, the *apatitic ore*. *Silexite* and *apatitic* ore types are most important ones, representing nearly 70% of the ore reserves.

Table IV. Ore type distribution and average grades

Ore types	Linear dist. %	Average grade by ore type (wt. %)						REO (%)
		REO	Fe ₂ O ₃	SiO ₂	TiO ₂	CaO	P ₂ O ₅	
silex	39.4	7.7	12.5	62.1	2.0	0.7	6.2	38.4
inter.	10.8	9.0	22.3	40.5	4.6	1.0	8.0	12.3
h.iron	20.4	7.5	32.4	22.9	9.8	1.5	8.8	19.4
apat.	29.3	8.1	21.5	21.5	6.7	10.8	12.6	29.9
total	100.0	7.9	20.3	39.9	5.2	3.8	8.8	100.0

silex - silexite; inter. - intermediate; h.iron - highly iron oxides; apat. - apatitic

Twenty-seven composed borehole samples, representing the above ore types, were then submitted to a standard beneficiation process test. The results, presented in the Table V, show that all four ore types replied satisfactorily to the established process. The average recovery of REO was 66%, at 19.5% REO grade.

Table V. Final products characteristics for the borehole samples

	Ore Types				Average
	silex.	inter.	h.iron	apat.	
N. of samples	9	3	7	8	27
Grades wt. %					
REO	23.2	15.1	17.6	17.5	19.5
Fe ₂ O ₃	21.2	30.5	39.2	30.5	28.6
SiO ₂	23.3	17.4	8.3	9.3	15.5
TiO ₂	1.7	4.1	4.3	4.0	3.2
CaO	1.1	1.2	1.5	6.8	2.9
P ₂ O ₅	10.4	8.5	9.7	11.2	10.3
Al ₂ O ₃	5.7	8.8	5.8	3.0	5.3
REO / Fe ₂ O ₃	1.1	0.5	0.5	0.6	0.8
Recovery %					
Weight	24.9	32.2	35.1	32.5	30.0
REO	60.2	72.3	83.2	66.9	68.2

silex - silexite; inter. - intermediate; h.iron - highly iron oxides; apat. - apatitic

Hydrometallurgical tests

Preliminary results of hydrometallurgical tests showed that the monazite can be easily leached at relatively low temperatures with small sulfuric acid consumption and, simultaneously, avoiding a larger incorporation of iron in the leached solution (<5%) (Barros, 1999). This unusual condition is probably related to the particular characteristics of monazite - usually very small crystallites with a very high specific surface area.

Results of sulfuric acid leaching at room temperature from the final products of the mineral dressing borehole samples are presented in the Table VI. The presence of silexite associated to monazite expressively degrade the REE recoveries for the leached solutions attained at room temperatures (<50%), while for *highly iron* and *apatitic ores* the recoveries figures are above 70%. Ore types with major amounts of silexite material demands for higher temperatures in the hydrometallurgical

process. Consequently, for the adopted conditions, the global recovery for the two ores types with silixite material are around 30% and for the other ones are around 55% in average.

Table VI. Summary of the REE recoveries in the mineral and hydrometallurgical processes for the borehole samples

	Ore Type				average
	silix.	interm.	h. iron	apat.	
N. samples	9	3	7	8	27
REE distr. %	38.4	12.3	19.4	29.9	100.0
<i>Mineral processing average recoveries (%)</i>					
Weight	24.9	32.2	35.1	32.5	30.0
REO	60.2	72.3	83.2	66.9	68.2
<i>Hydrometallurgical tests at room temp. - REE recov. %</i>					
	47.3	41.3	70.6	86.6	61.5
<i>Global REE recoveries (%)</i>					
	28.6	29.9	51.7	57.6	41.9

silix - silixite; inter. - intermediate; h.iron - highly iron oxides; apat. - apatitic

CONCLUSIONS

Corrego do Garimpo represents an important world REE resource with 1.12 Mt of REO at an average grade of 7.6% REO. Monazite-rhabdophane are the major REE-bearing minerals; it usually occurs as microcrystalline aggregates with crystallites in the order of a few microns in diameter, sometimes presenting colloform textures. Goethite, quartz and apatite are the main gangue minerals.

The detailed study of ore characteristics led to the understanding of previous failures of ore dressing studies, and provides the guidance to an unusual technological approach.

The proposed method is based on the strong and natural tendency of the monazite to break up easily and consequently to concentrate in the finest size fraction. The method comprises successive scrubbing and hydrocyclone classification cycles, and generated concentrates with average grades near of 20% REO and recoveries above 65% of the REE contents.

Once developed this mineral dressing process for bulk samples, the ore characteristics variability within the whole mineral deposit was evaluated. Four different ore types could be recognized based on their mineralogical and physical properties.

The established mineral process was evaluated by 27 standard tests of the borehole samples representing the four ore types, followed by sulfuric acid leaching at room temperature of the attained products. The mineral dressing results confirmed the good performance of the proposed processing method, while the presence of silixite associated to monazite expressively degrade the REE recoveries for the leached solutions (<50%), despite the fact that for the *highly iron* and *apatitic ores* the recoveries figures are above 70%. The ore types with major amounts of silixite material demands for higher temperatures in the hydrometallurgical process.

Consequently, for the adopted conditions, the global recovery for the two ores types with silixite material are around 30% and for the other ones are around 55% in average. Further hydrometallurgical studies from bulk samples must be performed in order to optimize the process and improve the REE recoveries, particularly for the ore types with an important presence of silixite material.

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