

Geometallurgy study of the Catalão I Nelsonite bodies aiming to increase the niobium production

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Abstract

Increasing the recovery of the niobium metal contained in the Nelsonite rocks presents a great challenge, considering the standards and the production targets of the China Molybdenum Company (CMOC) that produces phosphate and with tailings material, concentrate niobium minerals. At Chapadão mine, located in Goiás, a mid-west Brazil's state, the weathering profile reaches up to 100 meters and the ore is subdivided into three basic types, from top to bottom: Oxidized (OX), Top Micaceous (TM) and Base Micaceous (BM). In this study, samples from these three main bodies of Nelsonite were collected and tested in laboratory scale to identify which weathering level is more favourable to niobium concentrate production. In the niobium concentration process, there can be metal losses that can jeopardize the recovery of the niobium crystals. To evaluate these losses microscopy analysis was performed using samples from industrial plant survey. The results from flotation batch tests showed that BM presented the higher mass recovery and production capacity. According to the mineralogical results the main niobium losses were identified in the barite concentrate from apatite circuit and in the screening stage in the Niobium Plant feed. The batch test results showed that adjusting the cut size of the Niobium Plant there is a potential niobium recovery upgraded to 90% from Ba-pyrochlore, and, adding the barite concentrate product as an additional mass in the tailings feed, it will result together in more than 1 t/day of niobium concentrate final product, reducing the losses and utilizing better the ore blend recovery potential.

Keywords: Geometallurgy; Mineralogy; Recovery; Tailings; Niobium; Pyrochlore.

1 Introduction

There are different definitions of geometallurgy in the literature, but most of them include geology, mining and metallurgy in some way [1-6]. Geometallurgy is a multi-disciplinary approach and professionals from different areas need to work together to integrate the information available. A general definition for geometallurgy can be related to a tool aiming the integration of geological, mining, metallurgical and environmental data in a spatial model to forecast mineral processing plant production.

Nelsonites are known to be rocks of magmatic origin from correlated magmas with carbonatitic mantle plumes and are basically composed of magnetite, apatite and phlogopite, in this order of mineral predominance [7].

Although, depending on their temporal formation, it is possible to observe different structure, mineralogy, particle size or texture in different nelsonitic bodies, as showed in the Figure 1 [8].

This lithology contains various valuable minerals such as apatite (phosphate), magnetite (iron), pyrochlore (niobium), rare earth minerals and more rarely chalcopyrite-bornite (copper). The carbonate complexes of Araxá and Catalão are richest in which the nelsonitic rocks are mineralized in pyrochlore [9].

Chapadão mine, located in Goiás, a mid-west Brazil's state, is a mine belonging China Molybdenum Company (CMOC) and is the object of this study. Due to

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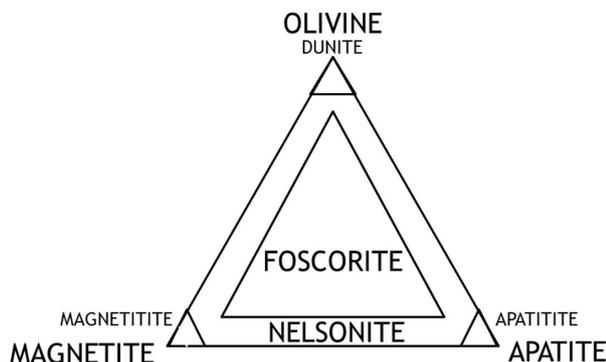


Figure 1. Foscoritic rocks diagram classification [8].

the great geological and mineralogical variability of the nelsonitic bodies, its behaviour in beneficiation processes is anomalous and depends on the pyrochlore mineralization, the nature of the grains of this mineral and its weathering degree. Thus, to ensure the recovery and production of niobium, it is necessary to characterize each type of nelsonite outcropping in order to ensure a better cost-benefit for the company.

Previous geometallurgical studies mapped the principal nelsonite rock's and divided them in different groups based on grade and recoveries. These results made possible the selection of areas where metal niobium production potential was evident [10]. Rangel [11] built a simulator to forecast the production of Catalão mine based on mineralogical information of different lithologies blended in each pile that feeds the circuits. Statistical analysis showed a reasonable result obtained from the simulator when compared to industrial data.

This work was motivated by the imminent possibility of reducing the niobium losses in the phosphate circuit, which could add value to the concentrate of the niobium circuit, as well as updating the knowledge regarding the valuable mineral of interest. Several samples were taken from outcrops with different weathering conditions in the mine and were tested in laboratory scale. In addition, samples were collected from industrial circuits in order to understand the behaviour regarding the nature of niobium-bearing minerals present in the samples. The goal of the study was to characterize the nelsonite orebodies at different levels of weathering, to understand the metallurgical results and to identify niobium losses in the Phosphate circuits and propose solutions to recover it.

2 Materials and methods

2.1 Samples

Three samples of nelsonitic ores were collected at different weathering layers to perform laboratory flotation batch tests: oxidized (OX), top micaceous (TM) and base micaceous (BM). The samples were collected using the method

of channels and trenches. The sample size corresponded to 5 meters of slope length, resulting in 50 kg of material. Each sample was quartered generating a 3 kg aliquot, which was the mass needed for the bench testing in the phosphate characterization route. These samples were collected and tested in laboratory scale to identify which weathering level is more favourable to niobium concentrate production, indicating the best material to constitutes the ore blend to feed the plant.

In the niobium concentration process, there can be metal losses that can impair the best recovery of the niobium crystals. Because of it, samples from industrial plant were also collected to investigate the possible niobium losses in each process stage using microscopy analysis. These other samples were collected to perform microscopy analysis: plant feed (PF), low intensity magnetic separation tailings (MT), barite concentrate (BC), apatite concentrate (AP) and Niobium Plant feed (NF). Each sample was quartered generating a 1 kg aliquot, which was the mass needed for the mineralogical testing in the microscopy lab.

2.2 Mineralogical analyses

The mineralogical analyses were conducted in the Microscopy Center at the Universidade Federal de Minas Gerais (UFMG). X-ray powder diffraction analyses were performed on a Scanning Electron Microscope - JEOL JSM - 6360LV equipped with high vacuum secondary electron detector, low and high vacuum backscattered electron detector, EDS (energy-dispersive X-ray spectroscopy) detector and an EBSD (electron backscatter diffraction) detector, plus a FEG - Quanta 200 FEI Scanning Electron Microscope equipped with a secondary electron detector, backscattered electron detector, transmitted electron detector (STEM), Pegasus: EDS and EBSD, operating at 30 kV voltage, beam current greater than 100 nA, resolution of 1.6 nm at 30 kV in high vacuum and ESEM-™ mode, 3.5 nm at 3 kV at low vacuum, focal length: 3 mm to 99 mm, 12x magnification (at longest working distance) at 1,000,000x at high and low vacuum.

The mineralogical tests were performed to obtain the following results: mineral EDS spectra, a detailed imaging sequence, the sample modal mineral distribution, the estimated chemical composition of the constituent minerals, the liberation degree for the main minerals of interest, the mineral particle size distribution as well as the percentage distribution of the main chemical elements.

2.3 Laboratory flotation batch tests

Figure 2 shows the process flowsheet considered for this study.

Table 1 shows the reagents dosage and operational variables considered in the flotation tests.

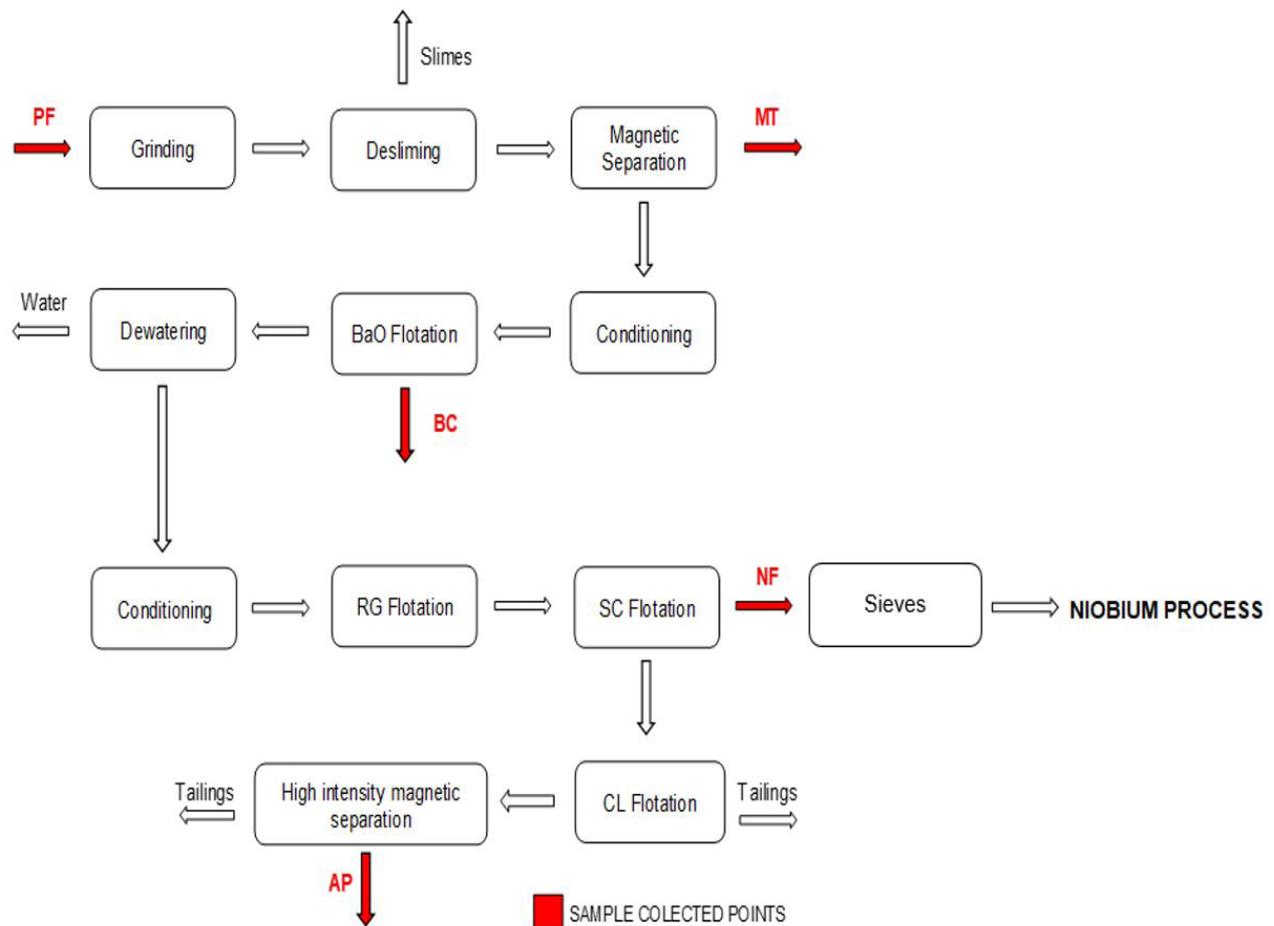


Figure 2. Laboratory batch test process flowsheet.

Table 1. Reagents dosage and operational variables considered in the flotation tests

	Reagents	C1	BaO	C2	C3	RG	SC	CL
Dosage	Starch (mL)	5			40			
	Lioflot (mL)	6					10	10
	Flotisor-071 (mL)	100				5		
	Lupromin (mL)	4	0					
	Flotanol (mL)	1		0				
Variables	Weight Solids (%)	-	-	47	47	47	30	30
	Rotation (rpm)	1200	1200	1200	1200	1200	1200	1100
	pH	9.5	9.5	9.5	9.5	9.5	9.5	9.5
	Conditioning (min.)	03:00		05:00	02:30			
	Flotation (min.)		02:00			02:00	01:30	01:15

The collector and depressor dosages were fixed for all flotation tests. The conditioning was named as C1, C2 and C3.

The samples were ground to obtain 80% passing in 212 μm (P_{80}), different size adopted in industrial circuit (149 μm). This modification was made based on mineralogical analyses performed with the samples collected from industrial circuits in 20L buckets.

3 Results and discussion

3.1 Industrial plant survey

Figure 3 shows a mineral map of a sample collected from the phosphate circuit feed. The colours represent the following minerals: Yellow - Apatite, Gray - Quartz, Red - Ilmenite, Green - Hematite, Blue - Pyrochlore.

According to the picture below it was possible to see that the principal ore minerals are in great majority free from intrusions and the apatite, quartz and pyrochlore minerals have a nice liberation grade percentage, what is favourable for the concentrate production mass.

Table 2 shows the mineral liberation grade of following flows: (MT) low intensity magnetic separation tailings, (NF) Niobium Plant feed, (BC) barite concentrate and (AP) apatite concentrate. Most of principal niobium minerals do not be liberated and recovered in MT because of the low percentage from free surface grain. The other stages presented more free surface grains that could be recovered.

Table 3 shows the mineralogical analysis for Ba-pyrochlore minerals according the cut size adopted. 100% of Ba-pyrochlore have less than 212 μm , but the process cut-size was 149 μm . Considering an aperture in 149 μm , 60% of Ba-pyrochlore present in the material was discarded

according to mineral release assays. Thus, changing the cut-size to 212 μm would generate 90% of Ba-pyrochlore fed according to mineralogical analysis.

3.2 Laboratory batch tests

Table 4 shows the flotation results for OX, TM and BM weathering layers.

The OX showed a poor result for apatite, generating a concentrate with only 10% of mass recovery and a

Table 3. Mineralogical analysis for Ba-pyrochlore minerals according to size distribution

Mineralogical Analysis	Cut-size (μm)	
	149	212
Ba-pyrochlore lost (%)	60.0	10.0
Ba-pyrochlore recovery (%)	40.0	90.0

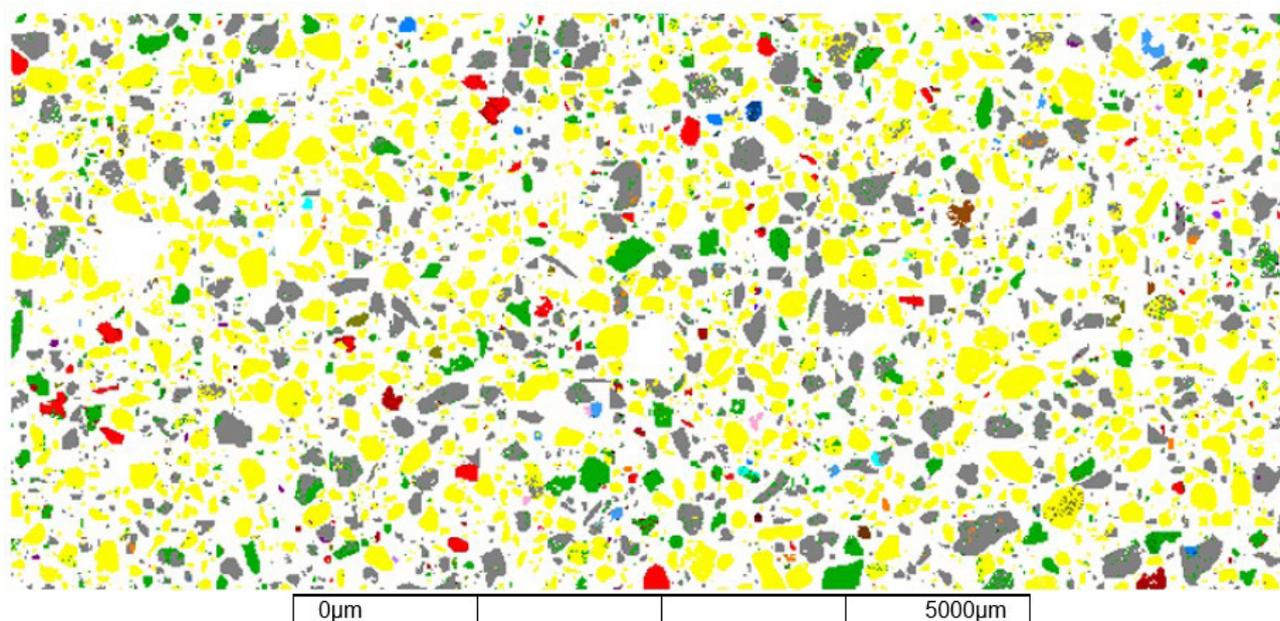


Figure 3. Mineral map of a sample collected from the phosphate circuit feed.

Table 2. Mineral Liberation Grade of (MT) low intensity magnetic separation tailings, (NF) Niobium Plant feed, (BC) barite concentrate and (AP) apatite concentrate

Minerals	%	MT	NF	BC	AP
Pyrochlore	Free	4.0	9.0	24.0	20.0
	Binary	39.0	44.0	64.0	48.0
	Ternary	57.0	47.0	12.0	32.0
Ba-pyrochlore	Free	2.0	71.0	32.0	50.0
	Binary	46.0	14.0	32.0	39.0
	Ternary	52.0	15.0	36.0	11.0
Zirconolite/Zirkelite	Free	1.0	48.0	37.0	26.0
	Binary	5.0	25.0	28.0	52.0
	Ternary	94.0	27.0	35.0	22.0

global process recovery of only 39%. For niobium, the target of this study, the product of interest, which is the scavenger tailings, presented a content of 0.33% from niobium oxide, which is relatively low considering the feed content targeted for the Niobium Plant. In addition, the mass that would be directed to the tailings was remarkably low, equivalent to only 4.5% of the total sample mass. In terms of the niobium distribution, the loss of the metal in the slimes and magnetic tailings was significantly high. Thus, it is possible to state that the OX will unlikely meet the necessary specifications for apatite concentration.

The TM showed an extremely poor result for apatite, generating a concentrate with only 10% mass recovery and a global process recovery only 37%. For niobium, the scavenger tailings presented a 0.60% from niobium oxide grade, which is significant considering the tailings feed target. However, the mass that would be directed to the tailings was incredibly low, equivalent to 1.0% of the total mass of the sample. Similar to OX results, the TM will unlikely meet the necessary specifications for apatite concentration.

The BM showed a significant result for apatite, generating a concentrate with only 9% of mass recovery, but with overall recovery of 53%. Regarding niobium, the scavenger tailings, presented an outstanding niobium content of 5.92%, considering the feed content target for the Niobium Plant. However, the mass that would be directed to the tailings was low, equivalent to 5.0% of the total mass of the sample. Analysing the distribution of niobium it can be observed that the metal loss in the slimes and magnetic tailings was high but too much less than the other weathering levels samples.

Table 5 shows the differences between the cut-size considered in the initial project (149 μm) and the cut-size adopted in batch flotation tests with the three samples of nelsonitic ores from different weathering layers (212 μm). There is a potential increase of 0.46 t/day of final niobium concentrate production changing the cut-size.

In terms of barite mineral concentrate, an interesting niobium loss was identified. The mineralogy showed that 50% of niobium in the feeding stage comes from Ba-pyrochlore and 32% of it is free. In particle size, 100% of Ba-pyrochlore is less than 38 μm .

Table 6 shows the capacity estimation considering the gain feed rate around 39 t/h that correspond of an additional daily production in the niobium circuit of 0.58 t from niobium concentrate.

4 Conclusions

The results from flotation batch tests showed that BM presented the higher mass recovery and production capacity. However, the metal losses in beneficiation process

Table 4. Flotation tests results for OX, TM and BM

%	OX	TM	BM
Mass Recovery	10.0	10.0	9.0
Global Recovery	39.0	37.0	53.0
Niobium oxide	0.33	0.60	5.92
Mass Feed	4.50	1.00	5.00

Table 5. Niobium production changing the cut-size feed

Capacity	Cut-size (μm)	
	149	212
Niobium production (t/day)	5.00	5.46

Table 6. Mineralogical analysis resume from Niobium circuit feed adding Barite concentrate

Capacity	Niobium Circuit Feed	Adding Barite Concentrate
Total feed (t/h)	125.0	164.0
Niobium production (t/day)	5.00	5.58

can masked this potential. Only with the microscopy analysis results from plant survey samples it was possible to identify the reason of this possible losses and identify an opportunity to increase the niobium production. The niobium observed in the BC stage sample was lost because the Ba-pyrochlore was dragged together a barite and apatite crystals because most of them are in a size less than 38 μm . In NF stage sample, the problem was identified in the sieve, because according the mineralogical analysis the Ba-pyrochlore that feeds the plant had about 212 μm as cut size, but the circuit is constituted by screens with 149 μm aperture resulting in 60% of these minerals being discarded.

The results indicated an increase in niobium circuit production about 1.04 t/day from niobium concentrate, being 0.58 t/day from barite concentrate niobium recovery and 0.46 t/day from changing the cut-size of the niobium circuit feed.

The geometallurgy program was fundamental to quantify the niobium ore available in the deposit and to generate information of great importance for mapping of process opportunities aiming to increase niobium recovery and production.

As suggestion for future studies the magnetic tailings shall be investigated by analysing the assays per size fraction and trying to optimize the recovery of valuable minerals using classification stages.

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