MINING, ORE PREPARATION AND FERRO-NIOBIUM

PRODUCTION AT MINERAÇAO CATALAO

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Summary

This paper briefly explains the different operating steps involving mining, ore preparation and standard ferroniobium production at Mineração Catalao de Goiás.

Introduction

The Catalao carbonatite is located in the Municipality of Ouvidor, Catalao County, in the Southeast of the State of Goiás, at a distance of about 20 km from the town of Catalao - geographical coordinates are 18° 08' Latitude South, 47" 48' Longitude West, Figure 1.

The oldest lithoestratigraphic unit in the area is constituted of granitic-gnaissic complex with intercalated amphibolites. Stratigraphically higher are the micashists and quartzites of the Araxá Group. Both units were intruded by the alkaline carbonatitic pipe which forms the Catalao Dome where the ore body is located.

The dome has a thick layer of weathered residual material above the fresh carbonatite. The weathering process dissolved and removed the carbonates which were part of the original intrusive.

The residual material contains the ore body associated with a large variety of primary and secondary minerals.

Among the primary minerals the following are of importance: pyrochlore, apatite, magnetite, titanomagnetite, ilmenite, monazite, perovskite, baryte and sphene.

Among the secondary minerals the following are significant: collophane, svanbergite, rhabdophanite, wilkeite, ancylite, vermiculite, florencite, anatase, limonite, goethite, quartz, goyazite, strontianite, clay minerals.

The company, Mineração Catalao de bias, (MCGSA), was established in September, 1970, commenced production of concentrate in May, 1976, and production of ferroniobium alloy at the beginning of 1977.

The claim belonging to MCGSA measures 381.7 ha and includes two ore bodies, both are approximately circular with a diameter of 450 m.

The ore body which at present is being mined, has a reserve of 4.2 x 10^6 t of ore with an average content of 1.20 percent Nb_2O_5.

The second body, which now is being studied in detail, comprises 22 x 10^6 t of ore with an average content of 1.07 percent Nb_2O_5.

Simultaneously with the studies of the second ore body, geological studies of the fresh rock started and four drill-holes have been completed, totalling 900 m.

Mining

Due to an erratic ore distribution regarding Nb_2O_5 content and behavior of the ore in the concentrating process, the deposit has been divided into blocks of 25 m by 25 m and 5 m depth. The drill-holes are located on the extremes of these squares as well as on the intersections of the diagonals. This means that the influence distance of each drill-hole is 17.68 m. From these drillings information about geological, chemical and ore dressing behavior is obtained. From the block's average Nb_2O_5 content, and the overall recovery obtained from laboratory beneficiation tests, the recoverable kilos of Nb_2O_5 per ton of ore are calculated for this block. This

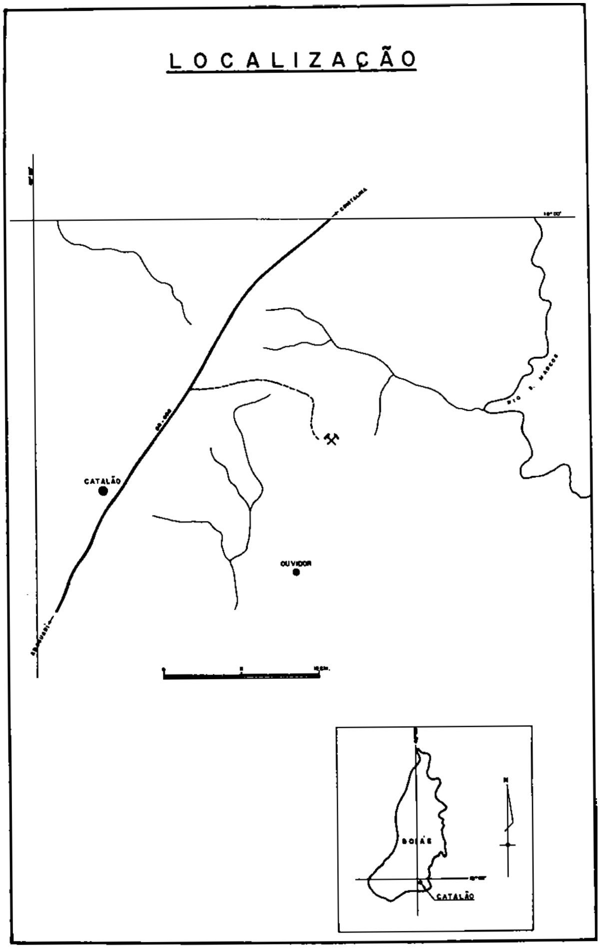

Figure 1. Location **map** of Mineração Catalão de Goiás S. **A.**

procedure leads to a good knowledge of the deposit and the figures of re-covery at ore extraction. Having in mind the improvement of the concentration process, the ore is submitted to a preliminary homogenizing operation. This involves the formation of lots with 120.000 t, corresponding to three months' feed to the beneficiation plant. These lots are, on average, composed in such a manner as to show a production of 5.8 kg Nb_2O_5 per ton of ore.

Once the blocks which will make up the lots are defined, the mining operation is easy. It should be noted that mining an open pit type of a weathered ore. The following steps are taken:

1. Ripping
2. 81111-Dozing
3. Loading
4. Transporting

The first and second steps are done with Caterpillar tractors; the loading is done by front wheel loaders and the transport is done by off-road trucks.

Mineraçao Catalao de Goias uses the following mining equipment:

02 D8K Caterpillar
02 Front Wheel Loaders - 966 Caterpillar
01 Bull-Dozer - 120 B Caterpillar
04 Off-road Trucks - R-22 Terex
01 Road Sprinkling Truck - Chevrolet

A general view of the Open Pit Mine is shown in Figure 2.

Figure 2. General view of open pit.

Ore Dressing

The ore dressing procedures include crushing, ore preparation, flotation, separation and leaching.

Crushing, Blending and Reclaiming

Ore from the lots on storage ground is transported to the crusher through an 80 ton capacity silo, equipped with a 305 mm (12 inch) fixed grate. A mechanical feeder leads the ore to a vibratory screen with 38.1 mm (1 1/2 inch) opening. The oversize goes through a jaw crusher. The undersize and the crushed material are separated at 12.7 mm (1/2 inch), the oversize being passed through an impact crusher. The -12.7 mm (-1/2 inch) fraction is led to two piles of 7.500 t capacity each, through a tripper on an overhead conveyor belt. Each pile capacity, equivalent to six days' ore feed to the mill, is reclaimed through the bottom (by means of a tunnel) to a flux regulating silo, Figure 3.

Ore Preparation

The ore is fed into a spiral classifier through a constant weight rate feeder. The classifier's underflow goes to a (2.4 m by 4.2 m) ball mill.

The milled material is pumped through a magnetic separator and the non-magnetic fraction is subjected to a second classifying step.

The classifier's overflow is subjected to a first desliming step in 152 mm (6 inch) cyclones. The underflow containing 65 percent solids by weight is subjected to two scrubbing steps and is again deslimed in 102 mm (4 inch) cyclones. The underflow is now prepared for flotation, being introduced into the conditioning tanks. The overflow from the 152 mm (6 inch) cyclones is led to separation in cyclones with 40 mm diameter, where particles larger than 5 μ are recovered. This fraction is cleaned (in the 40 mm cyclones) and then conditioned to be fed into the flotation cells. A general view of the ore dressing plant is shown in Figure 4.

Flotation

The conditioned pulp is led to a rougher circuit consisting of 20 Denver Sub A - no. 24 cells. The pulp has 35 weight percent solids and the pH is held at 4.0.

The concentrate is subjected to four cleaning stages in counter flow to the mix from the first stage; the roughs being recirculated with the new feed, Figure 5. The pH is gradually lowered to 2.0.

Typically the concentrate has the following composition:

Component	Wt %	Component	Wt %
Nb_2O_5	50.00	SiO_2	1.20
Fe_2O_3	7,00	P_2O_5	1.40
TiO_2	4,50	Al_2O_3	3.00
MnO_2	2,50	S	0.07

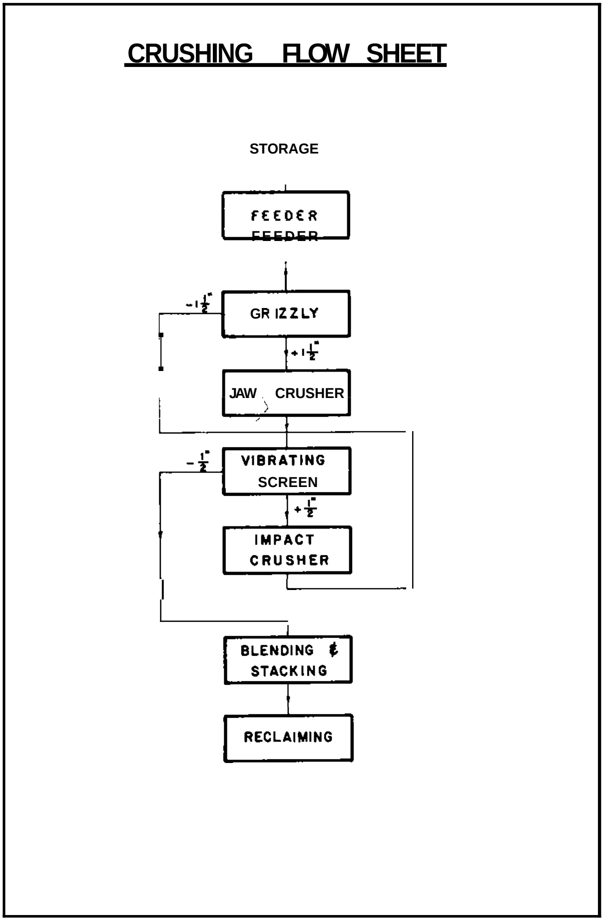

Figure 3. **Crushing flow sheet.**

Figure 4. General view of ore dressing plant.

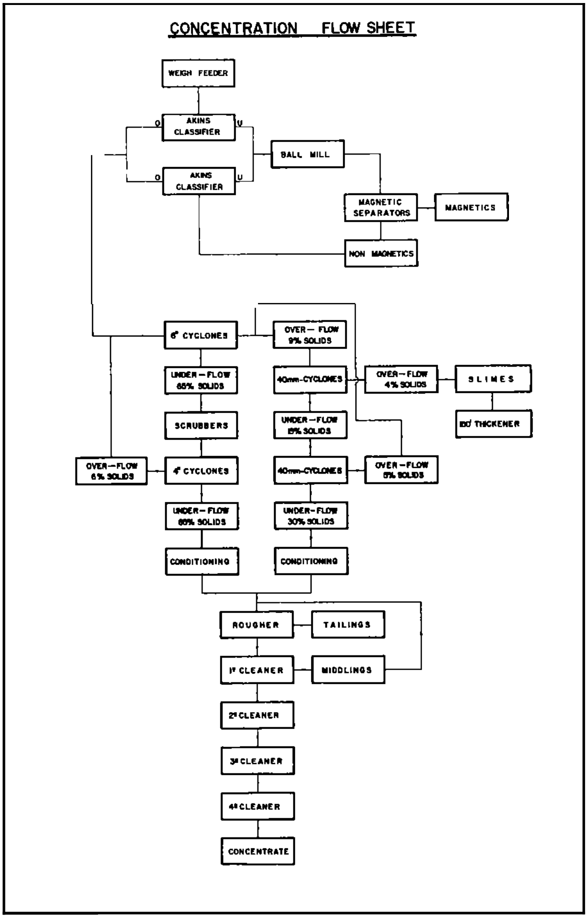

Figure 5. Flotation flow sheet.

Typical Balance:

Product	% by weight	Nb_2O content %	Nb_2O distribution %
Magnetite	35	0.42	13.0
Slimes	14	1.30	16.0
Tailings	49.9	0.53	23.0
Concentrate	1.1	50.0	48.0
Feed	-	1.14	-

Leaching

The leaching process is outlined on the flow sheet, Figure 6. The high P_2O_5 content in the flotation concentrate would lead to higher than allowed P contents in the final ferro-alloy. This P_2O_5 content is mainly due to the presence of secondary phosphates and to a lesser degree to the presence of apatite.

A leaching operation is performed in two steps at this stage.

Hydrochloric Acid Leaching. In batch reactors, an HCl solution of 5 moles per liter is prepared and the concentrate is added to form a pulp of 50 weight per cent. This pulp is stirred and heated with steam to a temperature of 80 C and kept at this temperature for two hours.

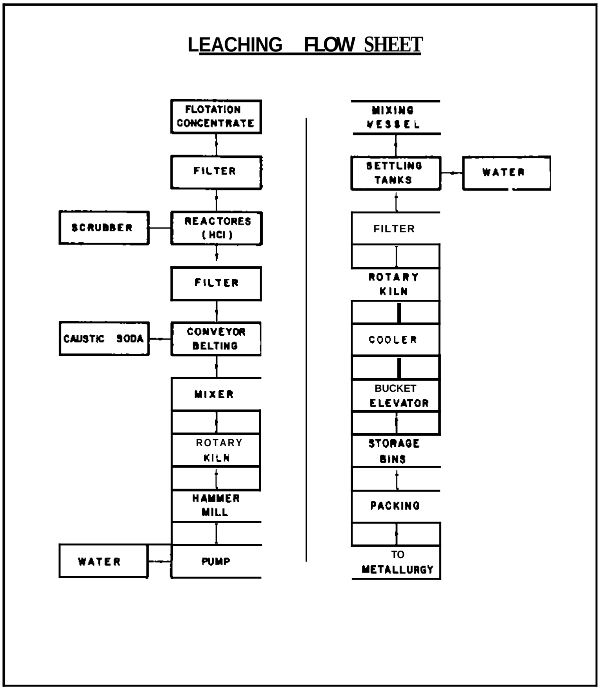

Figure 6. Leaching flow sheet.

The solids are decanted and washing water is added three times, until excess acid is removed. The pulp then is pumped to a drum filter to remove water. The HCl attack leads to hydrogen chloride and chlorine gas evolution which is exhausted and scrubbed, protecting the environment, Figure 7.

Sodium Hydroxide Leaching. To the filtered concentrate, 30 percent by weight sodium hydroxide is added with a small addition of water to form paste. This paste is taken to a rotary kiln and heated to 300 C.

The sodium phosphates which are formed are removed as water-soluble salts. The kiln discharge has water added to a pulp consistency and is stirred for two hours and then pumped to decanting tanks for a renewed solid/liquid separation. To optimize the elimination of the phosphate and sodium salts present, this operation is repeated four times. After the last decanting step, the pulp is pumped to a filter where it is again dewatered, awaiting a subsequent calcining step.

The concentrate is fed to a counter-flow calcining rotary kiln on a conveyor belt. To assure the proper removal of impurities the concentrate is heated up to 750 C, remaining a minimum of five minutes above 700 C. The concentrate discharge is cooled inside a rotating drum cooled by water on the outside. Once cool, the concentrate is released into a silo from where it is loaded into drums, sampled and weighed into lots of 3,200 kg.

Quality control is based on the 3,200 kg batches of concentrate.

Production of Standard Fe-Nb

The Fe-Nb is produced at Catalao by autogeneous aluminothermic smelting. The sampled lots of concentrate are assayed for the aluminium consuming oxides, as well as other impurities. Based on these values and on thermodynamic as well as empirical criteria, the prescription is calculated, namely quantities of Al powder; iron oxide, burnt-lime and fluospar to be added to the pyrochlore concentrate. The charge is mixed in a double cone mixer, resulting in a total reagents blend of about 4,800 kg per burn-off, resulting from two mixer loads.

Normal production rate is five burn-offs per day one after the other, Figure 8. To compensate for concentrate fluctuations, each reaction batch is composed of one part of each of the five final concentrate batches.

The blend is transported by overhead crane to the firing bank. This consists of cavities formed in common silica sand. Steel strip formers support the "mold" having the volume of the final products of reaction (alloy plus slag). Since the transition from reagents to products of reaction is accompanied by a large decrease in volume, the excess of reagents is accomodated in a steel cylinder lined on the inside with magnesite bricks having the same inner diameter of the steel strip liner.

The charge composition takes into account the following criteria:

- Enough reducing agent (aluminum) must be present to assure a good recovery of the contained Nb. However, the Al content of product must be within required limits.

Figure 7. Gas and vapor s r bbi g

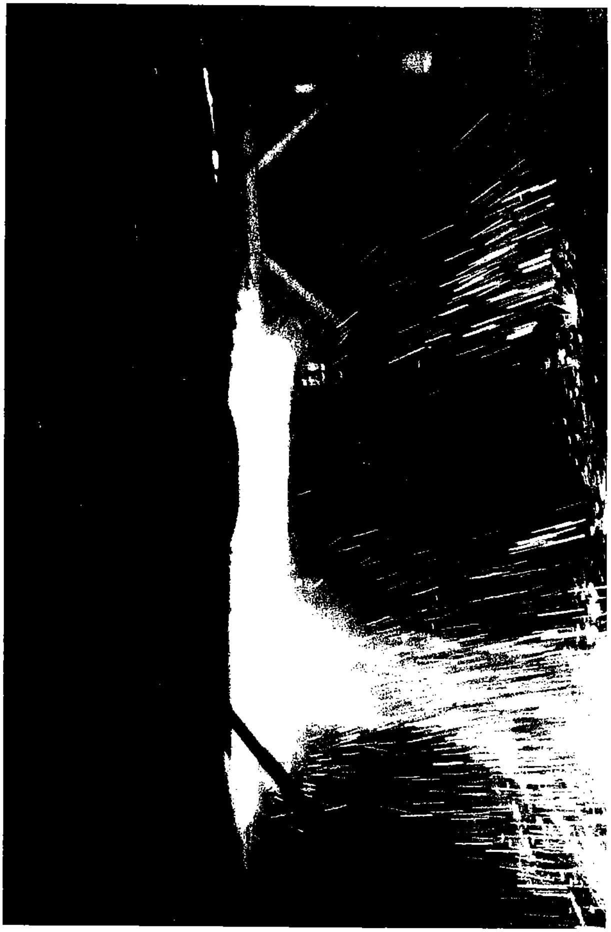

Figure 8 Thermite reaction.

- Enough heat to be released in order to have a good metal/slag separation as well as being able to achieve sufficient temperature to assure thermodynamic conditions to lower the levels of certain impurities in the alloy. Heat release per batch has to be limited to a level where the reactants are not projected out of the reaction vessel.

- Enough fluxing agents to assure a fluid slag also capable of dissolving certain impurities. Fluxing agents are inert and heat absorbers so their addition has to be kept within limits.

The thermite fumes are collected through a hood, to a manifold leading to a wet scrubber and exhaust fan, Figure 9.

Each firing lasts about 20 minutes. Immediately after the reaction has ceased, the hood is removed and the cylindrical liner is taken away, before the complete solidification of surface layers of slag. The products of reaction stay in the mold for about 20 hours to assure complete solidification of alloy and slag. At Catalao a sequential order of firings is used. In other words, only one batch is fired at a time. The firing bank has ten firing stations; five positions per day are used alternatively.

The solidified mass of alloy and slag is removed by the overhead crane from the reaction mold, after about 20 hours' time. The alloy button (about 1.700 kg) is inspected and cleaned with pneumatic hand chippers to remove adhering slag and lining material. The five buttons are then subjected to crushing, screening and sampling.

The crushing section consists of a Blake type crusher (45 cm by 35 cm) working as a primary on a closed circuit with a second jaw crusher (42 cm by 30 cm) and a four tier screening device conforming to final sizes required. Samples are taken from the infeed to the screening device, and are representative of the alloy resulting from the five firings. The metal's assay indicates Nb content and recovery (together with the weight of alloy obtained) as well as the impurity levels.

The final commercial lots are composed of this already assayed alloy stock but are again sampled on final packaging by an outside sampling surveyor who indicates the weight of the lot and particle size. The Nb content is calculated on MCGSA's assay of this sample. Duplicates are sent to the customer when required, and kept at MCGSA for reference purposes.

The plant as described has a capacity of more than 3.000 t of alloy per year.

Typical chemical composition is (wt. percent):

Nb	65	Si	0.80	Ti	0.60
Ta	0.50	Al	1.90	Sn	0.04
C	0.07	P	0.13	Pb	0.25
Mn	2.50	S	0.04		

Maintenance of Facilities

The diversity of equipment used, at a relatively isolated location, necessitates a fairly well equipped shop. MCGSA is equipped to maintain, modify and even build some of the equipment in use. To date, experience indicates that this capability has been very useful, both to assure the

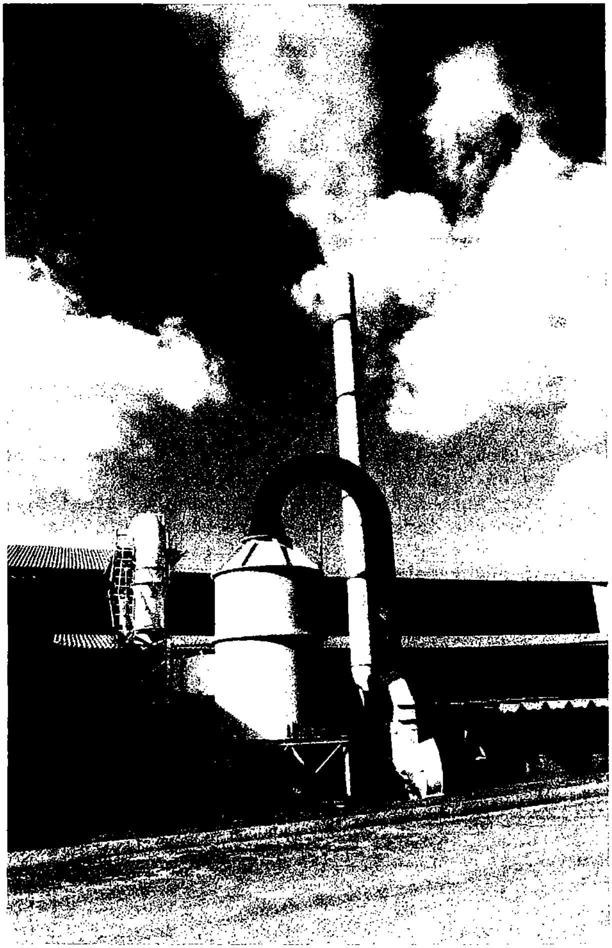

Figure 9. Thermite fume scrubber.

dependability of the operation, as well as facilitating modifications to the whole process as know-how is gained.

Quality Control

Sampling is done by each productive unit. Both manual and mechanical sampling is done. Samples are dried, ground, and then sent to the laboratory, where two analytical methods are available.

X-Ray Fluorescence (XRF)

Depending on the materials involved and the contents of the elements to be assayed, either diluted-and-ground-tablets or fused samples, are prepared.

Wet Methods

Some elements are determined by wet methods. Also, Nb and Ta on shipped product are determined by the wet, classical ion exchange method. This sector also helps the XRF by establishing standards for calibration purposes.

Research and Development

At this point in MCGSA's growth, research and development efforts are focused on process improvements, economical recovery of different mineralizations, and studies of by-products. In this connection an ore dressing laboratory with models of all ore dressing steps in the industrial plant is available and working nearly 24 hours per day.

Promising techniques are transferred to a pilot plant, capable of working continuously with a capacity of 700 kg per hour. The procedures proven in the pilot plant have their parameters then transferred to the industrial operation.

This sector also works in connection with the microscopical examination of minerals and also helps the industrial plant by supplying the following services, among others:

1. Sieve analysis
2. Slimes determination
3. Acid and alkaline leaching trials
4. Sample preparations

Overall Programs

The first priority is the constant improvement in recovery values of the surface ore body.

Secondly, plans are being prepared to begin trials to recover pyrochlore from the unweathered carbonatite.

On a longer time scale, it is being kept in mind to diversify the final Nb containing products, into higher purity Nb compounds and alloys.