ORE CHARACTERIZATION AND PROCESSING PLANT REMEDIATION

FOR A BRAZILIAN TIN MINE

By

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# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgments</td>
<td>2</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>3</td>
</tr>
<tr>
<td>Project Statement</td>
<td>4</td>
</tr>
<tr>
<td>Objectives</td>
<td>4</td>
</tr>
<tr>
<td>Chemical Composition and Ore Characterization</td>
<td>5</td>
</tr>
<tr>
<td>Mining Method Evaluation</td>
<td>13</td>
</tr>
<tr>
<td>Recovery of Fines</td>
<td>25</td>
</tr>
<tr>
<td>Future Work</td>
<td>32</td>
</tr>
<tr>
<td>Resources</td>
<td>33</td>
</tr>
<tr>
<td>References</td>
<td>34</td>
</tr>
<tr>
<td>Appendices</td>
<td>37</td>
</tr>
</tbody>
</table>
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Executive Summary

To further understand the separation process used by CSN-ERSA in Brazil, ore characterization of final concentrate samples was determined through Energy Dispersive Spectroscopy (EDS) testing. Characterization of each concentrate shows a significant amount of heavy metal contamination; a result of inefficient gravity separation.

CSN is looking to implement a mining method suitable for extracting ore at the Village site. The three options of mining methods are open-pit with gravel pumping, dredging, and a conveyor system. The conveyor system is recommended as the primary mining method because conveyors can upgrade production capacity, along with minimizing capital and annual costs. Also, they provide path adaptability by operating in steeper terrain.

Gravity separation methods and recommendations for mineral processing at the Taboquiña site is discussed. These include spirals, hydrocyclones, Knelson, Falcon, and tables. The final recommendation is a combination of methods, with variation depending on focus. Much like current operations, spirals and hydrocyclones can receive most of the material. For recovering fines, installing a Falcon gravity separator is recommended. The currently reprocessed middling could see improvements if a table separator were installed. For recovering tin lost in the tailings, it is recommended to use a Falcon separator.
Project Statement

The purpose of this project is to characterize the site’s ore, through analyses of mineralization, chemical composition and metallurgical processes, as well as to determine an appropriate mining method for a new site. Using the data collected, we will gain a better understanding for the expectations of the plant and be able to remediate the recovery of the current processing plant, along with providing a mining method recommendation. This will be completed by the end of April 2017 at a work cost of $33,166.50 and an approximate total cost of $44,716.50.

Objectives

1. Characterization of ore and tailings.
2. Evaluate the most feasible mining method for the Village site.
3. Remediate the recovery of fines from the mining and processing process.
4. Create a recovery plan for tailing dam material.
5. Create a detailed report for the project, and presentation for Design Day.
Chemical Composition and Ore Characterization
This relates to Objective 1

Introduction
A total of 72 Energy Dispersive X-Ray Spectroscopy (EDS) spectra were analyzed using Scanning Electron Microscopy (SEM) instrumentation. The 72 spectrums that were analyzed consisted of the four concentrate samples: Ilmenite, Columbite, Rich Columbite, and Cassiterite. Tests and analyses took place in the University of Arizona and were conducted with the help of Isabel Barton, a mineral resources research scientist. Through EDS analysis, we were able to determine the mineral characterization of each of the samples, displaying not only the targeted ore, but also the contaminants that were carried along with them. Though there are many strengths to this characterization approach, there are also some limitations to this technique that will be discussed in the theory portion of the report.

Theory
By producing a direct interaction between an electron beam and a target sample, a series of different emissions take place, including x-rays. By separating these x-ray emissions into energy spectrums, we have the ability to identify the abundance of different elements. Accelerated electrons emitted from the instrument also allow for the backscattered electrons to represent imaging, known as BES images, of the samples, as well as displaying their topography and morphology. Knowledge in chemical composition furthers the analyses of these spectrums to uncover the samples’ structures. Below is Figure 1.1, a sample of an EDS spectrum from the ilmenite concentrate sample as well as its BES shot in Figure 1.2.

![Figure 1.1: Ilmenite sample EDS spectrum (Sample1_EDS1_003)](image-url)
Though this analysis used SEM instrumentation, shown in Figure 1.3, an integrated EDS system was used to gather the sample data. Using an EDS detector, energy emitting from a targeted sample is captured and absorbed in a crystal through ionization which then yields free conductive electrons that produces a variety of electric charges. The absorption of the x-rays converts the individual energies into electrical pulses of proportional corresponding size. Every element produces its own electrical pulse, making it possible to differentiate the different elements contained in a targeted sample.
Strengths
EDS systems provide almost instant identification of elements when spotting small ranges within a sample. This is one characteristic that makes EDS classification a great tool for acquiring quick, quantitative results. In addition to nearly instantaneous classification, the system has the ability to recognize a sample when given origin or possible contents. This strengthens the ability for the software to classify elements and easily point out elements of contamination.

Limitations
Through the use of EDS detectors, many times there are overlaps of certain elements. In higher energies, this becomes increasingly usual where individual peaks can correspond to multiple elements. To combat this issue in classification, the software is equipped to accommodate the targeted sample with a questionnaire before testing, to predict the sample’s contents. This limitation becomes a bigger issue when operating with samples of unknown origin. Origin of the samples, however, is well known along with possible sample contents.

Confidence
Given the strengths and limitations of an EDS system, it was determined that this method of testing was still a strong and reliable method for determining the chemical composition of the samples. This conclusion was based on prior knowledge of origin and apparent concentrate of each sample, as well as the strong basis of knowledge from the SEM operator of this analysis.

Experimental Procedure
Each sample was placed on a carbon plated testing strip, as shown in Figure 1.4. Attached to each carbon plate of samples, an overlying copper strip is placed. The strip is then placed into the specimen chamber.
and into the SEM machine. Ventilation of the chamber should be on for this to continue. The electron beam should be placed 15-20 mm above the sample before commencement. After the sample is placed into the chamber and clipped onto the specimen cartridge, the machine door is shut. After some questioning from the computer system about the sample conditions and apparent composition, the production of electron images begins. These images are produced from what are known as secondary electrons; previously mentioned as the necessary component to producing BES Imaging.

![Figure 1.4: Sample preparation with Isabel Barton](image)

Imaging and data analysis for the four concentrate samples were done in bulk and spot modes in different areas on the carbon spots holding the samples. The use of both methods is equally useful in data collection. However, in order to achieve a more accurate analysis of each sample, spot mode is the method to use. Bulk spectrums usually hold a wide variety of wave peaks, including waves emitted from the carbon plating, especially in samples with high contamination where there is more than the apparent sample. Figures 1.5 and 1.6 below show a comparison between bulk and spot analysis through EDS spectra.
After spectral analysis is achieved through the system and operator input, the software generates a quantitative table, as shown in Table 1.1. A separate analysis requiring knowledge of chemical composition by the operator takes place with the generation of these quantitative tables of element abundance. The result of these analyses is the composition of each spectrum generated as a result from the bulk or spotting method.

<table>
<thead>
<tr>
<th>Chemical formula</th>
<th>mass%</th>
<th>Atom%</th>
<th>Sigma</th>
<th>Net</th>
<th>K ratio Line</th>
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<td>O</td>
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<td>74.46</td>
<td>0.09</td>
<td>120861</td>
<td>1.0096349 K</td>
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<tr>
<td>Al*</td>
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<td>22512</td>
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<td>0.08</td>
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<td>7.54</td>
<td>0.12</td>
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<td>1.0423715 L</td>
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<td>100.00</td>
<td></td>
<td></td>
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Table 1.1: Quantitative results from a spectrum (Sample1_EDS1_001)
Results

Spectral images and quantitative tables resulting from EDS analyses are located in Appendix A. Using and compiling the results from the quantitative analyses, the following tables were created to show the amount of apparent concentrate and contamination within each sample. Results are based on the 72 analyzed spectra. Spectra containing the apparent concentrate were placed under ‘Apparent Concentrate.’ Spectra containing minerals that were not the apparent concentrate were placed under ‘Contamination.’

Table 1.2: Quantitative results of EDS analyses for samples 1 and 2
Table 1.3: Quantitative results of EDS analyses for samples 3 and 4

Table 1.4: Summary of quantitative results by sample

Future Proposals

This report focuses primarily on the four sample concentrates (Figures 1.2 to 1.4), which gives a great representation of the final product. To understand the full effects of each step in the separation of ore, a wider research study should be conducted. The research study could potentially involve EDS testing of samples from each step of the process, from feed material to final concentrate, including tailings. This study could give a more accurate estimate of where ore is being lost and, in contrast, where it is more effectively separated. The depth of this proposal is much deeper than the analysis of just the concentrates, due to the addition of both the number of tests and the additional analysis of separation effectiveness of each step to reach the final concentrate.

Conclusion

Results show a wide variety of dense minerals, such as zircon and topaz, contaminating each of the concentrate samples. Though this report is only determining the characterization of each sample, it can be concluded that from these results that the gravity separation techniques currently being used have some major issues. As the tables above show, the ilmenite sample is full of columbite concentrate, the columbite sample is full of ilmenite, and the cassiterite concentrate is full of columbite. Each of these
samples contain their own significant amount of contamination. The samples, however, do show a ‘cleanness,’ with each grain showing no intergrowth between the concentrates. This means that the sample particles themselves are clearly separated from one another, but are still being carried into the final concentrate. To further understand and remediate this separation issue, the ‘Recovery of Fines’ report of this project expands on possible optimization plans through different methods.
Mining Method Evaluation
This relates to Objective 2

Introduction

Given the nature of the deposit, there are three possible methods of extraction/transportation: open-pit with gravel pumping, dredging, or the use of a conveyor system. First, the area in which the ore will be extracted must be taken into account. In this case, the location is the Village mining site in the state of Rondônia in the north-western region of Brazil, as shown below in Figure 2.1.

Figure 2.1: Location of CSN-ERSA Project

The primary mineralization type of the Village region is associated with intense pneumatolytic alterations that originated tin-bearing quartz veins. However, the bulk of tin production from Rondônia has been mined from secondary, detrital deposits in alluvial, eluvial and/or colluvial accumulations derived from the weathering and erosion of the tin bearing greisen. This greisen and the mineralization in the Santa Barbara Hill are the main sources of cassiterite (and for minor amounts of columbite-tantalite). These deposits lie at depths of 0 to 35 meters and the potential reserves are approximately 6,000 tonnes of Sn.

Mining Methods

Open-pit

The most common method of mining, known as open-pit, uses a mechanical shovel and haul trucks. This process of mining a near surface deposit occurs by means of a surface pit excavated using one or more horizontal benches. The bench height is usually decided by the economic reach of the mining equipment used in the mine. As a rule of thumb, the bench height is equal to the economic bucket height of an excavator. The thickness of the orebody, its dip, and the thickness of overburden also play an important role in determining the bench height.

Since the Village deposit has a depth of at least 20 meters to an extension of possibly 35 meters, this fits one of the criteria of the open-pit method. However, the geotechnical conditions of the overburden and the orebody must also be taken into consideration. In this case, the deposit is alluvial, which means that it
consists mainly of silts, sands, clays and gravels, along with large amounts of organic matter and the ore (Cassiterite), which is mixed in with this material. This raises questions about the geotechnical conditions, which would later determine the ultimate pit depth in terms of safety and economic justifications.

However, there are some disadvantages of using the typical shovel and truck set up. First, depending on the capacity of the processing plant, ERSA might need more equipment to achieve it. This means that the company would have to hire more personnel to meet these requirements, and due to the mining location this might become difficult to accomplish. This would leave the company in a situation where the mining and hauling equipment is holding up the processing plant and the possible profit. Also, depending on the life of mine (LOM) and processing plant renovations/optimizations, equipment might need to be bought in the future to comply with the capacity as mentioned before.

**Gravel Pumping**

Gravel pump mining includes, but is not limited to, the use of water monitors, sluice boxes, palongs, and gravel pumps. Water monitors are high water pressure jets used to break down the bench face. The water-earth slurry mixture then runs down the pit to a sluice box that separates large earth using rails. Material small enough to pass through the sluice box then goes through the gravel pump that then transports the material to a palong. The palong is a large structure with an incline with rifles perpendicular to the incline that holds the heavier material. The heavier material, tin, is held by the rifle with concentrate assays of 50% to 60% while the remaining slurry runs down to a dam or river bank where the water can be recycled and reused. The material is then passed to jigs and sent to the concentration plant for further processing.

However, the Village pit at ERSA’s mine site can incorporate a gravel pump mining method without the necessity of constructing a palong. ERSA’s current mining equipment already separates the slurry material through the use of sieves, which is the palong’s purpose. The slurry pit and excavators would not
be in use due to the gravel pumping method having no use for them. This, however, is not entirely true for the use of all excavators though. Since the clayey deposits are hard for the water monitors to break down, excavators would be used to dig up and break down the clayey material. This method also has no use for a separate slurry pit since all slurry accumulates at the main pit.

The Village pit has recently acquired haul trucks and the gravel pumping method would have little to no use for this new machinery. Traditionally, gravel pump mining was used due to its low capital cost and ability to pay off those costs within the first few years of production, though overall this mining method uses a large amount of energy to run the pumps and monitors. In addition to the energy used to run the monitors, moving the large monitors across the bench face is very inconvenient and maintenance is costly due to the large amount of slurry on the bench floors. Another drawback to gravel pump mining is the production of high maintenance tailings that accumulate in large amounts.

Planning to mine Village using gravel pumping methods, if ultimately considered, would run the project using a combination of open cast and a gravel pump. This is much like its current method without the use of a separate slurry pit, or with one that is more strategically placed in order to reduce the moving costs of materials. Taking into consideration head loss due to pumping from a height, the slurry pump should be positioned the closest to the ore body vertically.

![Gravel pumping station](Image)

**Figure 2.3: Gravel pumping station**

**Cutting Suction Dredging**

A Cutter Suction Dredger (CSD) is one of the most common mining methods in the tin mining industry. It is widely used for alluvial material including compacted clays and hardpans. A CSD is a stationary dredger placed on the water surface that is equipped with a rotating cutter head for cutting and fragmenting hard soils. The soil is sucked up by means of dredge pumps, and discharged through a floating pipeline to a deposit area. To apply this mining method to the Village mine site, an artificial lake
needs to be made prior to mounting the CSD on site. The change from a multi-unit dry mining operation to a single unit dredge mining operation requires a complete change of operational mindset. The wet dredge mining operation requires longer preparation and planning in advance. The one unit operation does not allow a flexible planning. Instead of a daily adaption, the planning period requires a significant amount of time.

As shown in the topographic map below (Figure 2.6), the Village site is located in between hills and the measured elevation gap on this site is 21 meters with a peak elevation of 129 meters and a low of 108
meters. The total area of the Village and Village TV sites are estimated to be 0.77 and 3.05 square km, respectively. Since the required water depth to float dredging machinery and its operation is 2 m, the total water required for the artificial lake is calculated to be 7.64 million cubic meters. The existing water in the sites are not accounted into consideration for required water amount. The average annual precipitation in state of Rondônia in the last 10 years is estimated as 1327.25 mm and open water evaporation loss for future lake is evaluated to be 1332.25 mm. The water loss related to weather condition is significantly lower to overall design criteria since the difference between evaporation loss and annual precipitation are fairly small. In order to feed the concentration plant with a capacity of 3,600 tonnes per day, one cutter suction dredge with an engine power of 308 HP and discharge diameter of 10 inches is required. The diesel engine dredge is recommended considering annual fuel cost vs. electricity cost analysis. The detailed calculation can be found on Appendix.

CSDs offer high machine availability with high efficiency rates of up to 95%. They also offer high rates of production along with a lower tonnage cost. The ore can be hydraulically transported via pipeline to the existing concentration plant. Since dredging is a single unit operation, the required number of personals to monitor the operation is considerably low. The number of personnel is estimated to be six, assuming three shift of 8 hours per day with two personnel on site all times. The annual labor cost is calculated to be $69,120.00 USD.

There are number of studies needs to be performed to sustain artificial lake for LOM before implementing dredging operation on the Village and Village TV sites. Despite the sustainability studies, slime studies need to be performed for operation ability purpose. The small particles that tend to settle on the bottom

![Figure 2.6: Topographic Site Map](image)
surface of the pond and reduce the loss of water can also be so abundant that they remain in suspension. Slimes differ significantly from turbidity, as turbidity trails will eventually settle as the oxygen eventually separates from the particles. They have shown to be able to take a percentage of the water volume and make the water not suitable for washing with separation technology.

Nonetheless, this method does not have the flexibility compared to open-pit mining and a dysfunction of certain parts could cause an operational shut down until fixed. Also, dredging requires a high capital cost compared to the other mining methods considered in this report. One of the main concerns is that the dredging equipment will not be able to mine the mother rocks if ERSA is planning to mine the existing mother rocks on the Village site. There are a number of practices in the tin mining industry in building artificial lakes to apply the CSD method. However, practiced mines have more than ten years of mine life and it is recommended to apply this method to mines with a higher LOM.

It is important to note the lake preparation work and water costs are not accounted into capital cost of the dredging mining method cost analysis. These factors should be in consideration for the final mine planning design. Addition to lake preparation construction work, surge bin is required to build to feed the concentration continuously since production stops at the end of every end of swing as well as when dredge itself to move forwards to adjust with mining face. The figure below (Figure 2.7) illustrates similar dredging machinery in delivery phase. The dredge can be shipped in 2-cargo size containers and should be fully mounted in at least 28 days.

![Figure 2.7: Cutter Suction Dredge in Shipment Phase](image)

**Conveyor Systems**

Conveyor systems provide a convenient method of delivering material from one place to another. Generally equipped with a belt system, conveyors may operate in different forms, with the most common being the bridge and chain conveyors. The Village pit at ERSA’s mine site has potential to incorporate a conveyor system as part of the mining method.
Implementation of a conveyor belt is dependent on a few different characteristics of the site. The main concern is the life of mine for the pit; if it is below approximately eight years, the capital cost of a standard conveyor system will not be offset. The ore deposit greatly determines the viability of implementation as well. Most often, conveyor systems require a crusher and a hopper to accompany the belt itself. The crusher makes the material suitable for transportation on the conveyor belt. However, because the deposit is alluvial, the material size is already fine enough to where the Village site would not require a crusher to accompany the conveyor belt. A simple hopper would be adequate in placing the excavated material on the belt, which would then be sent directly to processing.

Conveyor belts offer an alternative to the typical shovel and haul truck method of transportation of material to the processing plant. Some of the benefits of choosing a conveyor system is the higher amount of valuable operating time and operating time. Conveyors offer regular and systematic loading that greatly reduces the cycle time of transportation of the material. Conveyors are considerably safer than trucks, as they cause far fewer fatalities annually. Lower maintenance costs paired with less labor and energy requirements also make conveyors a reasonable choice. Since one of the major issues with the Village site includes finding enough employees to operate trucks, the conveyor system could be a potential solution to increasing equipment utilization and providing a more consistent means of transporting material to the processing plant.

However, there are some drawbacks to the addition of a conveyor rather than using haul trucks. The most important is the high capital cost, which reaches estimates of $300 per meter. As the processing plant cannot be moved, this would require the conveyor distance to be extended for up to 1,400 meters. If any piece of the conveyor is under maintenance, the whole operation is halted, which can be detrimental to meeting daily production requirements. It is notable that usually the belt can be fixed within one shift, so this will create a problem for meeting daily production requirements, but not monthly requirements. Many conveyors are inflexible in that once they are placed, they cannot be easily moved. This means that more planning and drilling may be required to know where to place the system to meet throughput requirements and optimize performance.

![Figure 2.8: Conveyor system transporting material to processing plant](image)
Proposed Processing Plant Location

The location of the plant shown in Figure 2.9 was determined by the proximity of the existing road, allowing for an easier transportation of the material, as well as because the location is approximately in the middle between the Village and Village TV sites (around three kilometers to each border). Picking this particular location near the ore body allows for excavation of the entire Village TV site, while also providing a space that is relatively flat, so minimal preparations will be needed before construction.

Cost Estimation & Assumptions

Assuming that the volume to volume workable ratio is the same for the Village and Village TV sites, Table 2.1 shows the estimated volumes, tonnages, and subsequent mine life for both sites, individually and combined. Cost estimation values for dredging, conveyor systems, and gravel pumping were obtained primarily from Cost Mine. Other numbers and calculations were provided by CSN. For the conveyor and dredge systems, the capital costs had to be scaled down to account for production requirements of 3,600 tonnes per day (150 tph). For all details in the calculations refer to Appendix B.
Table 2.1: Calculated Life of Mine for Village and Village TV given the Tonnage values from the PYORY files, and assuming a minimum of 3,600 tonnes per day.

(*Estimated assuming that the Volume/Volume Workable for the Village TV site is the same as the Village site. The actual number for Volume Workable for Village TV was not provided).

These calculations were made under the assumption of various parameters. The first of these assumptions is that the minimum mining and processing capacity is 3,600 tonnes per day. The life of mine is calculated based off of given reserves and the aforementioned capacity, while mining 350 days per year, 24 hours per day (3 shifts of 8 hours each day). The import cost was assumed to be 40% of the original capital of each equipment. Many of these values can be seen in Table 2.2 below. Costs are calculated using monthly values, which are multiplied by twelve to give an annual cost. The total cost for each mining method is the summation of the capital cost and calculated annual cost multiplied by the life of mine. All calculations for the total cost use the “workable” statistics, as shown in Table 2.3.

Table 2.2: Operational parameters
Table 2.3: Final Cost estimations for the Mining method systems and their separate components

**Mining Method Scenarios**

**Minimum Initial Cost**

In the case for the lowest initial/capital cost, the result was that a combination of Open-pit and gravel pumping would be the lowest, sitting at an approximate of $804,033 with a difference of around $300,000 to the next lowest initial cost. This system is similar to the one that is currently being used at the Taboquinha site, in which an excavator fills a truck that transports the material to a “slurry pit” which is then sent by pipe or hose to the processing plant.

**Minimum Operating Cost**

For the case of keeping the operational (Labor & Fuel/Electricity) cost to a minimum, the recommended method would be the dredge system with an annual cost of $326,240. While this system has a lower annual cost compared to the other systems, major preparation work has to be done prior to and during operation for the dredge be in operating conditions. These conditions are to be explained further in the next section.

**Minimum Labor Cost**

Usually, recent or new mining operations have a hard time finding people to work in these remote areas for extended periods of time. For this case, the recommended method would be the dredge system, since for the relatively small equipment the recommended number of operators per shift would be two people. This results in six people per day, which would cost the company an estimate of $69,120 annually.

**Minimum Changes to Current Operation**
Since the current operation is already a combination of open-pit and gravel pumping, the next feasible method would be implementing the use of a **conveyor system** with an approximate initial cost of $884,664. This system relies on being able to use one of the trucks (25 m³) and the CAT 320D2 excavator that CSN-ERSA currently has at the Taboquiña site. This conveyor system has been calculated to fit the minimum production requirements of 3,600 tonnes per day, thus resulting in a minimum distance of 1.4 kilometers of conveyor belts.

**Mining Method Evaluation**

**Open-pit & Gravel Pumping**

As indicated by Table 2.3 above, a combination of open pit and gravel pumping yields the scenario with the lowest capital cost. However, this does not take into account the slope stability and maintenance costs associated with it. Constant monitoring and maintenance of the walls and a water pressure system would amount to a cost greater than the effect of a low capital cost. In addition to the maintenance of the water pressure system, there needs to be enough mobility for the water monitor to move across the face of the pit. With gravel pumping, this becomes increasingly harder throughout the life of the mine due to the effect of slope and bench floor stability from the material running down to the gravel pump.

**Open-pit & Conveyor**

The combination of the open-pit and conveyor methods is an excellent choice for mining the Village site in the case that CSN only wants to make minor changes using the method of production at the Taboquiña site. All that would be required to initiate this method would be to buy and install a small capacity (150 mtph) conveyor belt that at minimum must span 1.4 kilometers. This conveyor system would largely eliminate a higher need for labor, as only occasional maintenance on the belt would be necessary. It is hard to find laborers willing to work on site, as well as finding skilled workers to operate the haul trucks. This method would reduce the amount of truck drivers and excavator operators needed to one each, making it a very efficient and consistent method, also if any part of the conveyor is to be repaired, this can be done in one shift, providing less downtime. Downsides to this method would be a higher capital cost and the effort it would take to import and install a conveyor system.

**Dredging**

As shown in Table 2.3, dredging comes with the benefit of low labor and fuel costs, and if solely compared to conveyor and gravel pumping systems (both combined with open-pit), this is the most feasible method. But as before mentioned, some conditions have to be met before a dredge can start to operate. First, the site has to be filled and kept to a certain water level, since each dredge has a minimum and maximum water level for operation. The change from dry mining to wet mining demands a complete operational mindset and requires weeks in advance mine operation planning compared to open-pit. Also, the flexibility of changing back to other methods are very low and costly. It is also important to note the artificial lake construction work and water cost are not accounted into capital cost estimation. It must also be considered that there is a possibility to obtain a used dredge, which would lower the capital cost of the machine significantly.
Operating Fleets by Method

Open-Pit and Gravel Pumping:
- 2 Mercedes-Benz Actros 4844K with a 25m³ dump-bed
- 1 CAT 320D2 Excavator with 1.2m³ bucket
- 1 Pump with an approximate flow of 38,000 liters per minute with a head of 30.5 meters. Possibly a Schurco Slurry | Z Series Gravel and dredge pump

Open-Pit and Conveyor:
- 1 Mercedes-Benz Actros 4844K with a 25m³ dump-bed
- 1 CAT 320D2 Excavator with 1.2m³ bucket
- Minimum of 150 mtph, 61 cm belt width with a rating of 330 lb/in width and 150 HP. Possibly a Sandvik | PC300

Dredging System:
- 1 Cutting suction dredge, diesel powered with at least 308 HP engine and discharge diameter of 10 inches. Possibly a SRS Crisafulli | Rotomite 6000 or an Ellicott | 370 HP “Dragon” Dredge

CSN-ERSA would need to contact the providers to exchange necessary information for more accurate details.
Recovery of Fines
This relates to Objectives 3 and 4

Introduction

Mineral processing has been an enormous area of research in the mining industry for the last century. Chemical engineers and material scientists are constantly coming up with new ways to better extract and collect the rare earth metals that are harder to obtain due to their size or other properties. With all the new technologies and methods available, it becomes a struggle for a mine site to choose which method will work best. The purpose of this report is to explore some of the different separation methods that can be used to process tin, and analyze which would be best for the CSN-ERSA Taboquiňha site. Methods selected for analysis in this report include: spirals, hydrocyclones, Knelson, Falcon, and tables; all of which use gravity separation. The concept of gravity separation is to use the density of the desired material to one's advantage and separate it from the “waste” material by letting gravity do the work. Some of these methods have more complicated ways of completing this task, but it can be noted that a combination of these methods will surely produce a better result than relying solely on one.

Methods

Spirals

Spiral gravity separation offers a simpler, yet still effective approach to recovery of desirable metals. With the use of a plain spiral system, a sample can be stratified based off of density. Through the spiral system, feed material is separated based on density by a combination of centrifugal force and heavy particle migration. This is much like the advanced systems, but with much less machinery. As the feeds flow down these spirals, the heavier material, that does not stay suspended in fluid, flows towards the center of the spiral where collection ducts are placed incrementally in order to retrieve the metals. A retrieval duct may also be split in order to separate even more, providing a high grade and medium grade material. The rest of the fluid flows around the outer end of the spiral and is collected at the bottom as tailings. The major problem with this system is its inability to collect finer particles. Anything below a certain particle size, combined with the density, will flow through the fluid as though it is waste material. The only way to counter this interaction is to lessen the fluid velocity, which would allow large particle waste to be collected. All in all, while the system offers an easier installment and lower capital cost, its efficiency and ability to collect all the fine material is significantly lower than its counterparts. Figure 3.1 explains the spiral separation methodology.
Figure 3.1: Spiral separation methodology

Hydrocyclones

Hydrocyclones are a widely used and accepted form of gravity separation. Hydrocyclones are the simplest version of gravity and centrifugal combination, using the shape of the spiral to enforce the centrifugal force. The separation occurs due to the density and particle size of feed material, with the most dense and large particles falling through the bottom of the cyclone, while the lighter and smaller materials are removed through the top.

Figure 3.2: Diagram of hydrocyclone separation
These processors are favored in the industry because they require a very small amount of space to install, and can maintain performance even at heavy feed volumes. The major drawbacks of these machines is that there is no way to capture fine particles, and light coarse material can still make its way through to concentrate. Even with these disadvantages, the hydrocyclone is a great start to any processing plant, and its use in the industry is widely accepted.

**Knelson**

As previously mentioned, there are multiple gravity separation techniques. The use of a Knelson concentrator has become widely accepted in the industry, and is one of the leading techniques for separating particles based off of density. The Knelson system works by using a rotating truncated cone. The cone is incremented by multiple ring partitions in order to collect high density material. The lighter weight particles will flow over top of the ribs, and be sent to the tailings facility as discharge.

![Figure 3.3: Knelson concentrator](image)

This system is widely used in gold mines due to gold’s density versus the particle matter it is usually found in. However, it may also be used in other systems. One of the drawbacks for such a system is the large quantity of fresh water required in order to keep the particles in motion and suspended in fluids. Due to this requirement, the system is not practical in areas that have do not have a water source. Figure 3.3 shows a visual of the process of the Knelson concentrator.

**Falcon**

Falcon concentrators are already being widely used across the mining industry. A Falcon unit consists of a smooth-surface truncated cone which rotates at very high speeds. Feed material is injected near the bottom of the apparatus, and due to the centrifugal force, it is split based off of density. High density material remains at the bottom of the machine and is collected through collecting ports.
Figure 3.4: Falcon concentrator during operation

The less dense material rises to the top and is flushed out to tailings facilities. Falcon units are already being used with a variety of different metals, including iron, tin, titanium and gold. Once the ore is analyzed and the differences in densities is calculated, the speed can be set in order to properly collect the metals. That being said, this system heavily favors consistency in feed material; changes in particle size could mean that some of the material is not collected. Like the Knelson concentrators, Falcon concentrators also require large amounts of water in order to keep the process running. Figure 3.4 gives an illustration of the operation of the Falcon concentrator.

**Tables**

Heavy metal recovery through the use of shaking tables has been in the industry for many years. The use of shaking tables also relies on the difference in densities between the metals and waste material. Essentially a shaking table consists of an apparatus that sends feed material down a sloped surface. Heavier material falls and remains at the top, while lighter material washes down to the bottom. These tables can either be smooth if the difference in density is large, or contain riffles (little grooves in which heavy material can be trapped). While these tables show very high recovery rates in many circumstances, they cannot process at rates which the other methods can. It takes time for the material to displace when the system solely relies on gravity and not a centrifugal force. While this may seem like a downside, it also offers the benefit of being able to recovery more fine material, as the fluid velocity is not nearly as high as the other methods. Although the process cannot handle large amounts of feed, it offers incredible benefits when used at the end of a production line to get the final separation between the concentrate and other materials that may have slipped through the concentration process. Figure 3.5 below is a diagram of the components of a typical shaking table.
Recommended Recovery Method

For the CSN-ERSA processing plant, there are many options. The main points of this recommendation will focus on the recovery percentage, as well as offering optional inclusions that could increase recovery. The main problem with the current system at Taboquínha is that fine materials are not recovered, this issue can be solved with the implementation of some new equipment. Specifically, the Falcon gravity concentrator. If the processing plant were adapted to include a Falcon concentrator to recover the fine material, the tin recovery would be greatly increased. In this system, the material would first be run through a hydrocyclone, to remove the majority of waste material that is less dense. After the hydrocyclone, a spiral separator would collect the most coarse and dense materials. This process would be repeated multiple times down the processing plant, changing small variables along the way such as the hydrocyclone size or the spiral steepness. All along this system, the tailing material would be sent straight to the Falcon concentrators.

After the hydrocyclones and spirals, the tailings would be sent to the Falcon concentrators. The particle size of any remaining tin material should be rather small by this point (Falcons operate best at a P80 of less than 100 microns) and therefore the Falcon should be able to operate efficiently. It may take some dialing in to get the Falcon to operate at the correct speed of rotation to gather this fine tin, but once this setting is found it requires very little operator attention, and can handle a large capacity. With all these processes, CSN should be able to recover the better portion of their tin.

The only addition CSN could make on top of these concentrators is the use of a table system for middling. The table system could be implemented to provide a different separation of the middling material, rather than just trusting the spirals and cyclones repeatedly. The amount of middling is not very large, therefore they could likely be processed using a table system. If a table system were to be implemented into the recommended flowchart (Figure 3.6) it would be installed to take the middling of the cleaner spiral. Of course, the table system is adjustable to the point that it should be able to separate any coarse waste material that may have found its way through, and it would be clearly visible due to the open system.

A drawback to implementing the table is the large amount of area it occupies, in addition to the need for an operator to make consistent checks in order to make sure it's operating correctly. In addition to the space it would occupy, the table system would also need to be covered. The area in Brazil receives heavy amounts of rainfall, which could disturb the sensitive system. The final recommendation would be to
implement the current system, with the addition of Falcon concentrators to increase the recovery of fine material; with the optional addition of a table system to help the separation of concentrate.

**Recommendation for Tailings Processing**

The current issues for the tailings at CSN’s site are solely due to the lack of ability to collect fines in past years. Implementation of new equipment would likely yield favorable results for recovering the fine material that is trapped in them. Now that the tailings have had time to settle and harden, the first step in the process for recovering the tin would be to rehydrate them, and recreate a slurry. This would a slurry or mixer tank to be installed; in which the tailings would be extracted, placed into the tank, and then mixed with water. As previously mentioned, the particle size for fines recovery should be around or less than 100 microns. After the material is rehydrated it could be pumped to the Falcon concentrator system. With the current flow chart recommendation (Figure 3.6) the three Falcon concentrators can handle 4,320 tons per day. With the normal operations producing 3,600 tons per day; the tailings reprocessing could be done at 720 tons per day, without any more processing equipment. This addition of the tailings to be reprocessed would add onto the current recovery percentage, and the benefits would be seen immediately.

![Figure 3.6: Recommended Processing Plant Flow Chart](image_url)
Economic Changes for Recommended Flow Chart

While building and making changes to a processing plant can cause a major setback for a mine economically, the benefits of the changes would surely be seen in the long run. Seen below in Table 3.1, the cost benefit of implementing a new system would be seen immediately. Even with a realistic view of increasing recovery from 48% to 68%, (other assumptions for the profit table can be seen in Table 3.2) the amount of profit increase in one year is nearly two million dollars. When combined with the extra material from the old tailings material, the figure jumps to three million dollars in profit. When looking at the situation in a more optimistic light, say getting the plant to recover 80% of the tin, we see a profit of three million a year without tailings processing, and over four million when the tailings are also included. The prices of the gravity separation equipment can be seen in Table 3.3. These do not include import cost, installation costs, or the amount lost during the setup of a new configuration, but even with those, the profit severely outweighs the costs.

<table>
<thead>
<tr>
<th>Processing Changes</th>
<th>Recovery Percentage</th>
<th>Recovery Amount (kg/day)</th>
<th>Recovery Value (US Dollars/day)</th>
<th>Profit Increase (US Dollars/day)</th>
<th>Profit Increase (US Dollars/year)</th>
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</thead>
<tbody>
<tr>
<td>Current Rates</td>
<td>48.00%</td>
<td>642.00</td>
<td>$12,775.80</td>
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<td>Proposed Circuit (Realistic)</td>
<td>56.00%</td>
<td>907.00</td>
<td>$18,049.30</td>
<td>$5,273.50</td>
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<tr>
<td>Proposed Circuit (Optimistic)</td>
<td>68.00%</td>
<td>1,051.00</td>
<td>$21,253.20</td>
<td>$8,477.40</td>
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<tr>
<td>Proposed Circuit w/ Tailings Addition (Realistic)</td>
<td>68 + 20 from tailings</td>
<td>1,051.00</td>
<td>$20,914.90</td>
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Table 3.1 Theoretical Recovery and Profit Changes for Implementation of Recommended Plant

Table 3.2 Assumptions in Recovery and Profits Table

<table>
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<tr>
<th>Equipment</th>
<th>Details</th>
<th># of units</th>
<th>$ / unit</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spirals</td>
<td>Diameter: 0.61 m, Single Start</td>
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<td>Diameter: 22.8 cm</td>
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<td>$5,168.00</td>
<td>$15,504.00</td>
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<td>Falcon</td>
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<td>$220,000.00</td>
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<td>Tables</td>
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<td>1</td>
<td>$85,140.00</td>
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<td>Sieves</td>
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<td>Total</td>
<td></td>
<td></td>
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Table 3.3 Estimated Unit Cost & Total Cost for Recommended Processing Equipment
Future Work

There are other opportunities to further develop this project in addition to aforementioned recommendations. The first and most notable area of future work would be continued laboratory testing, both mineralogical and metallurgical. At this point in the project, mineralogical tests have been completed on various concentrate samples for the Taboquiño site, as well as preparation work for metallurgical tests. While this testing has produced accurate data that is useful for characterizing the ore, more testing is needed in order to reach more detailed conclusions. Some of the future testing that could produce a vaster library of data would be to collect a wide variety of samples from different stages of the processing plant at the Taboquiño site and perform EDS testing. This would help to identify the areas of the processing plant that are responsible for losing the most ore and help to locate potential inefficiencies. More samples could also be pulled from the newer Village site in order to make comparisons with the Taboquiño area. This would allow for a better implementation of a mining method for Village. More metallurgical tests should be performed to verify the theoretical recommendations presented in the ‘Fines Recovery’ section of this report, as the data would give insight to which gravity separation technique is most effective to increasing the recovery of fines.

Lastly, the accuracy of implementing a new mining method at Village would be greatly improved with more concrete input parameters. Many assumptions were made within the ‘Mining Method Evaluation’ section of this report, so more time could be spent collecting appropriate specifications of equipment that is being used. This could be done by contacting equipment vendors and coordinating with current CSN employees.
## Resources

### Human Resources

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Contact info.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eric Ross Ballinger</td>
<td>Project Coordinator, Companhía Siderúrgica Nacional</td>
<td><a href="mailto:eric.ross@csn.com.br">eric.ross@csn.com.br</a></td>
</tr>
<tr>
<td>Henrique Villela Aroeira</td>
<td>Senior Analyst/Economist, Companhía Siderúrgica Nacional</td>
<td><a href="mailto:henrique.villela@csn.com.br">henrique.villela@csn.com.br</a></td>
</tr>
<tr>
<td>Isabel Barton</td>
<td>Research Scientist</td>
<td><a href="mailto:fay1@email.arizona.edu">fay1@email.arizona.edu</a></td>
</tr>
<tr>
<td>Junmo Ahn</td>
<td>Graduate Student and Research Laboratory Assistant</td>
<td><a href="mailto:jmahn87@email.arizona.edu">jmahn87@email.arizona.edu</a></td>
</tr>
<tr>
<td>Brennan Mallory</td>
<td>Sales Manager, Latin America, Sepro Systems Corporation</td>
<td><a href="mailto:brennan.mallory@seprosystems.com">brennan.mallory@seprosystems.com</a></td>
</tr>
<tr>
<td>Dr. Jaeheon Lee</td>
<td>Associate Professor, University of Arizona</td>
<td><a href="mailto:jaeheon@email.arizona.edu">jaeheon@email.arizona.edu</a></td>
</tr>
<tr>
<td>Dr. Brad Ross</td>
<td>Associate Professor, University of Arizona</td>
<td><a href="mailto:bjr@email.arizona.edu">bjr@email.arizona.edu</a></td>
</tr>
<tr>
<td>Cesar M. Lemas</td>
<td>Senior Student, University of Arizona</td>
<td><a href="mailto:lemasc@email.arizona.edu">lemasc@email.arizona.edu</a></td>
</tr>
<tr>
<td>Corbin Goldsmith</td>
<td>Senior Student, University of Arizona</td>
<td><a href="mailto:corbingoldsmith@email.arizona.edu">corbingoldsmith@email.arizona.edu</a></td>
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<tr>
<td>Benjamin Clarke</td>
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<td><a href="mailto:bclarke3@email.arizona.edu">bclarke3@email.arizona.edu</a></td>
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<tr>
<td>Munkhdemberel Batbayar</td>
<td>Senior Student, University of Arizona</td>
<td><a href="mailto:mugibatbayar@email.arizona.edu">mugibatbayar@email.arizona.edu</a></td>
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<tr>
<td>Jorge Barrera</td>
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<td><a href="mailto:jbarerra1@email.arizona.edu">jbarerra1@email.arizona.edu</a></td>
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*Table A: Human Resources (Names, Title and Contact info.)*

### Facilities

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<td>Department of Mining and Geological Engineering Conference Room</td>
<td>Microsoft Office Suite</td>
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<td>University of Arizona Mineral Processing Laboratory</td>
<td>The Rational Project Manager by Andrew Longman and Jim Mullins</td>
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<td>University of Arizona Library</td>
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</tr>
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<td>McClelland Laboratories Inc.</td>
<td></td>
</tr>
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</table>

*Table B: Facilities, Materials and Equipment used as resources*
References


http://mercedesbenz.com.br/pdfs/caminhos/Actros_4844_K.pdf


http://hotcopper.com.au/documentdownload?id=uOMxKKzFkiWRTLKhoROKAXjvQkAK4Qa0pmWKtJlJ2%2Fk%3D


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https://www.met-solvelabs.com/library/articles/mineral-processing-introduction


http://serc.carleton.edu/research_education/geochemsheets/techniques/SEM.html


https://www.scientific.net/AMR.634-638.3478


http://s7d2.scene7.com/is/content/Caterpillar/C10703981
APPENDIX A

CHEMICAL COMPOSITION AND ORE CHARACTERIZATION
SAMPLE 1

A1.1: Sample 1 Bulk EDS 001

A1.2: Sample 1 Bulk EDS BES

A1.3: Sample 1 EDS 1 001
SAMPLE 2
SAMPLE 3

A1.50: Sample 2 SEM Image 1

A1.51: Sample 3 Bulk EDS 001
A1.67: Sample 3 EDS 1 017

A1.68: Sample 3 EDS 1 BES
A1.72: Sample 4 EDS 1 001

A1.73: Sample 4 EDS 1 002

A1.74: Sample 4 EDS 1 007

A1.75: Sample 4 EDS 1 BES
A1.76: Sample 4 EDS 1 All Spectra

A1.77: Sample 4 EDS 2 001

A1.78: Sample 4 EDS 2 002
A1.94: Sample 4 SEM Image 1

A1.95: Sample 4 SEM Image 2
APPENDIX B

VILLAGE MINING METHOD CALCULATIONS
### A2.1: Conveyor Cost Estimation

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<th>Initial Cost</th>
<th>Annual Labor Cost</th>
<th>Annual Fuel Cost</th>
<th>Annual Cost</th>
<th>Operating Cost</th>
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<td>$1,863,316</td>
<td>$1,696,996</td>
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### A2.2: Final Cost Estimations for each mining method

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</table>
A2.3: Dredging Cost Estimation Part 1

A2.4: Dredging Cost Estimation Part 2

A2.5: Gravel Pump Cost Estimation
A2.6: Open Pit Cost Estimation

- Given Volumes for Village and Village TV:
  - Village: Waste: 19,379,000 m³, Ore: 2,520,628 m³, Total: 21,899,628 m³
  - Village TV: Waste: 41,359,000 m³, Ore: 2,793,632 m³, Total: 44,152,632 m³
  - Volume Workable: Village: 17,441,100 m³, Village TV: 37,223,100 m³

- Calculated Tonnage:
  - Village: Tonnage: 34,392,416, Workable Tonnage: 30,944,174

- Calculated Life of Mine:
  - Village: Life of Mine: 27.29 Years, Life of Mine Workable: 24.56 Years
  - Village TV: Life of Mine: 66.02 Years, Life of Mine Workable: 49.51 Years
  - Both Sites: Life of Mine: 82.30 Years, Life of Mine Workable: 74.07 Years

A2.7: Life of Mine Assumptions
A2.8: Life of Mine Operational Parameters

<table>
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<th>Category</th>
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<th>Tons/m³</th>
<th>Tons</th>
<th>Days</th>
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</tbody>
</table>

**A2.9: CSN Parameters**

1. What is the cost of labour for the mine site? This cost can on average, when we know the rates vary throughout the day. You need to calculate the power cost for the potential contract equipment. R $ 3,000.00 with benefits.
2. What is the average labor cost for a local shift worker? R $ 3,000.00 with benefits.
3. What is the average import cost and delivery fee to the mine? Does this change based on the equipment being imported or by it coming? As a general rule add 40% of the cost. Once we have a specific piece of equipment in stock with the vendors there can be a more precise quote calculation.
4. how much does it cost to hire new laborers to control the new equipment? (yet to be calculated)
5. Which equipment is being rented and which ones are currently rented? (i.e. trucks, excavators)
6. 2 excavators B200 0.7m³
   - 2 loaders B2000 2.0m³
   - 2 loaders 1,4000 2.5m³
   - 1 motor grader

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Eric Ross Ballinger
to me, Linda, Mug, Gerson, Cafine, Jorge, Henrique

4. How much does it cost to hire new laborers to control the new equipment? You can consider manac, carpenter, welder etc... R $ 5000.00 month including benefits.
7. What are the capacities and pulp density of the pumps that are feeding the mill? Today the pumping capacity of each line (there are 3) is around 75ton / hour.

Cesar,
Completing the previous email, currently we have 5 trucks 6x4 volvo vm260, 1 loader WA320, 2 excavators PC200 Komatsu, 1 tractor d61ex15.
Of these own equipment, the only one currently in a working condition but with limitations is the D61EX15.

Best,
Henrique