Managing ARD in a Gold Mine in the Vicinity of Paracatu Town, MG State, Brazil

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Abstract

This paper outlines the ARD control program conducted by Morro do Ouro Site, located in the municipality of Paracatu, Northern region of Minas Gerais State in Brazil. The program was an essential piece of the site strategic planning to approve the mining of a sulphide ore near to environmental authorities. The site early understanding of the potential environmental risks and integration of the ARD control actions in the mine planning process has been a significant differential that has allowed the site keeping its environmental license for the last 20 years with the additional benefit of significantly reducing closure costs.

Key words: managing, acid rock drainage, integration, mine planning, sulphides, acid forming, segregation, control of contaminant migration, acid neutralization capacity, planning, savings, closure costs.

Introduction

In the municipality of Paracatu, which is located in the Northern region of Minas Gerais State in Brazil, a carbonaceous phyllites rock hosts a gold mineralization, which originated the Morro do Ouro mine. The mineralized zone is formed by a package that varies between 80 and 100 m in the presence of stretched quartz veins, called "boundins". Gold is associated with carbonates (mainly Anquerite and Siderite) and some sulfides (Pyrite, Pyrrhotite, Arsenopyrite and lower concentrations of Sphalerite, Galena, and Chalcopyrite) that are associated with these quartz venules. 03 main types of ore have been characterized by the mine: CTBI oxide ores located on the top and B2, the sulphide ore on lower zones of the geological body.

The challenge of managing ARD at Morro do Ouro site is significant as the mine occupies an extensive area of 2,484 ha: mine pit with 931 ha operating less than 500 m of some neighboring communities and the two tailings dams (named Santo Antonio and Eustaquio) occupying 1,553 ha in total. This paper outlines the ARD research program implemented by Morro do Ouro site, how this research was translated into on the ground implemented solutions and the benefits of the implementation of this program.

The Morro do Ouro ARD Research Program

Since 1991, Morro do Ouro mining has been conducting research applied to the control of the acid rock drainage (ARD). By decision of the company's corporate technical group, the mining of the sulfide ore, named B2, could not be conducted if the process route that took into account environmental controls in the ARD process had not been previously defined. So that a dedicated team effort was initiated including the mine, process, dam and environmental areas to manage the issue.

By the end of 1991, the mine set its first program of static tests aiming to provide a preliminary identification of the acid generation potential on the sulfide ore. Preliminary ABA tests were conducted and results indicated that this potential existed.

In 1994, a dedicated laboratory was installed on site to conduct kinetic tests to evaluate the long-term acid generation potential and investigate potential covers and the required environmental controls (Figure1). The key objectives of these tests were:

Figure 1 *Laboratory built to conduct kinetic tests*

- To investigate different sulfide (sulfur) content in the final tailings and their potential for acid generation;
- Evaluate the possibility of addition of neutralizing material easily available in nearby areas of the site like calcite and dolomite limestone;
- Investigate the need for segregating the sulphides and their safe disposal.

In 1998, Morro do Ouro site started mining the B2 sulphide ore and had already its processing and environmental integrated route defined from the ARD research program. This included the use of a geological model with PAF and NAF materials information to manage the waste and sulphur grade in the ores fed in the plant, the segregation of the sulphides in the flotation process and stoichiometric addition of limestone to prevent acid generation from residual sulphides contained in the final tailings to be discharged in the dams.

In 2002, Ladeira et al. conducted a specific study to confirm the adsorption capacity of a local soil (red clay), which was previously tested in the lysimeter kinetic tests, to be used as a seal in the sumps bearing the sulphur concentrate. Maximum adsorption capacities of the samples were determined by a Langmuir type equation. Chemical and mineralogical characterization was carried out in order to determine the main minerals responsible for the adsorption process. The adsorption process proved to be high and was correlated with the presence of Al and Fe oxides.

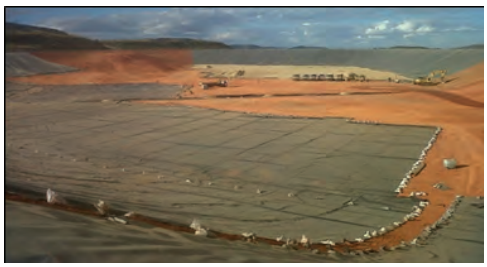

Figure 2 *Red clay used in construction of Specific Tanks*

Figure 2 illustrates the implementation of the local red clay as a seal in the specific tanks.

In 2015 the site initiated a field experiment with the purpose of evaluating the adequate cover for the Santo Antonio Tailings Storage Facility. The pilot-scale experiment consists in four 100-m2 cells which were installed with a trafficability layer of 1.5 m in both experiments and a storage and release layer with and without a hydraulic barrier. Monitoring of moisture profile and oxygen concentration trends within the cover trial plot commenced in May 2016. The instrumented trial cover plot is composed of four experimental cells that simulate two different covers. Two of the cells are embedded by lysimeters, which are lined by geomembrane so that percolated water is collected for flow measurement. The other two cells were installed without geomembrane so there is an interaction between tailings and the cover material, simulating the real scenario (control test). Data indicate the possibility of reducing the cover from the previously designed 3 m to 2.0 m with significant savings in closure costs. Refer to section 4.2 for other details.

Key ARD Control Management Actions Defined from the Research Program

Mine Pit Modelling to Identify NAF and PAF Ores

Initially, a detailed assessment of geochemical data was conducted using the geological database. Approximately 40,200 sulphur assays were conducted for individual 3m depth intervals and 4,500 acid neutralizing capacity (ANC) assays on 12m composite depth interval samples. These data indicated that the future mine rock (waste and ore) was of a low to moderate S and low to moderate ANC type.

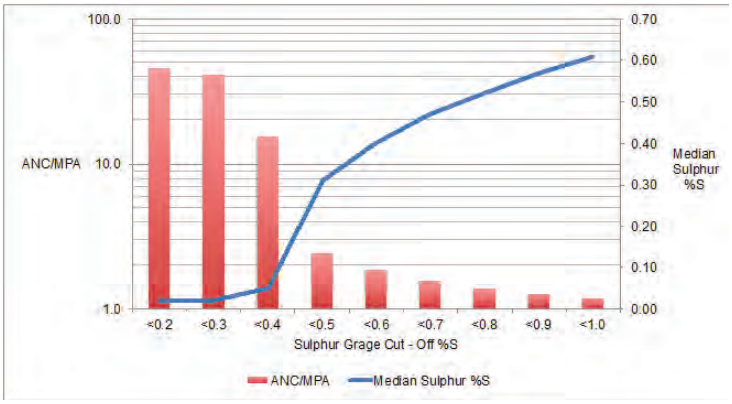

Figure 3 *ANC/MPA value and average sulphur content with increasing grade cut-off*

In addition, acid-base analyses using the Net Acid Producing Potential (NAPP) approach indicated that about 50% of mine rock was likely to be PAF and 50% was likely to be NAF. These data also demonstrated that the operational classification of waste rock for segregation was better based on NAPP, but in areas where ANC data was not available, a sulfur grade approach needed to be developed.

Figure 3 provides the basis for applying a risk-based approach to defining a workable and realistic S grade cut-off for NAF and PAF in the absence of ANC data. Since the ratio of ANC to MPA* (ANC/MPA) provides a measure of the factor of safety (FOS), it can be used in combination with NAPP to define the ARD risk associated with selected S cut-off values.

The ANC/MPA and median S grade clearly identify a step decrease in the FOS between a cut-off value of 0.4%S and 0.5%S. This indicates a far greater risk of PAF hot spots developing in the dump using a 0.5%S cut off compared to 0.4%S. Unlike process tailings or individual samples, a run-of-mine mixed waste rock dump requires a greater excess in ANC to minimize the risk of ARD.

From this assessment, Morro do Ouro site established the following criteria for the classification of waste rock in order to enable segregation and selective handling to minimize the risk of ARD during operations and post-closure:

- Non-Acid Forming (NAF): Total S ≤ 0.4%S or NAPP <0 KgH2SO4/t
- Potentially Acid Forming (PAF): Total S > 0.4%S or NAPP >5 KgH2SO4/t
- Potentially Acid Forming low capacity (PAF_LC): NAPP 0 to 5 KgH2SO4/t (Note that PAF_LC can not be identified using S only).
- *MPA = maximum potential acidity

These criteria were included in geology block model in order to proceed with the ARD management system at the Morro do Ouro site. This allowed the site to consider the segregation of wastes into the strategic business plan developed for the life of mine.

Plant Design to Ensure Recovery and Segregation of Sulphides

Segregation of Sulphides

The decision of separately store sulfide-rich carbon in leach (CIL) hydrometallurgical tailings from the lower sulfide bulk flotation tailing was one of the most important taken by Morro do Ouro site to control ARD. In this circuit, the flotation tailings are discharged to conventional tailings dams while the CIL tailings are discharged into engineered excavated sumps locally nominated as "specific tanks".

The flotation tailings are classified as non-hazardous waste according to Brazilian legislation (ABNT-NBR 10,004 Standard). The sulfide content of the flotation tailings is controlled within the Beneficiation Plant where gold and sulfide are recovered in the concentrate. Generally, about 40 to 60% of the sulfide in the ore is recovered resulting in flotation tailings containing generally less than 0.5%S.

The base and sides of the specific tanks are excavated into bedrock and lined with about 0.5 m of the local red clay. A low permeability geomembrane (HDPE - high-density polyethylene) is placed over the clay. The clay is

naturally rich in Fe and Al oxides and provides a good attenuation capacity to any potential seepage passing through the HDPE liner. Additionally, a seepage collection system and monitoring wells were installed beneath the specific tanks to early identification of any seepage through the structure.

CIL tailings are rich in sulfide sulfur (approximately 20% S) and contain other contaminants such as metal and metalloids, in particular arsenic. These tailings are disposed at a rate of 300 m3/h and maintained under water to minimize exposure to atmospheric oxygen and avoid ARD generation during operation.

Limestone Addition to Final Tailings

Morro do Ouro site implemented a limestone addition program at the Beneficiation Plants to minimize the risk of developing acid generating zones across exposed beaches and to control the solubility of arsenic. The acid-base characteristics of mill tailings are routinely monitored. In the case of Santo Antonio dam, this procedure was optimized to benefit ANC a couple of years before the tailings discharge ceased in that dam in order to increase the target ANC/MPA factor of safety to 1.5 and facilitate closure. Geochemical data of exposed tailings shows that the carbonate addition (as dolomite) has met its goal during the operational period and prepared the dam for a lower cost and more conventional closure (no complex cover required) (see detail in section 6). By avoiding acidic zones in the tailings, the solubility of metals and metalloids has been properly controlled.

Management Commitment to the ARD Control Program

The Morro do Ouro site management commitment to the ARD Control Program has been outstanding. Since the early stages of the program, management has proactively positioned supporting the control requirements. The ARD topic has been integrated in the site business planning and into the decision making process. The topic has been periodically discussed during routine meetings and provisions made accordingly. Around 95.3 Million Dollars have been spent with the ARD control program at Paracatu site including the construction of the specific tanks, reagents to recovery sulphides, consultancy support, geochemical assays and field trial tests in the last 6 years.

Figure 4 *Water quality of tailings dam downstream Santo Antonio and Eustaquio creeks*

Benefits arising from the Morro do Ouro ARD Program

Among the various benefits arising from the Morro do Ouro program, the preservation of water quality and the closure cost reduction should be highlighted.

Preservation of Water Quality

In the State of Minas Gerais (Brazil) the water quality limits are considered conservative (Class II Waters, Brazilian Federal Law CONAMA n° 357/2005) although the legislation recognizes that some regions might have higher limits due to the local geological background as long as scientific based studies are conducted to demonstrate it.

Morro do Ouro site has been very successful in managing its effluents and ensuring water quality within the conservative Class II limits adopted in Brazil or keeping them at least below the background referential limits established for the region and accepted by the agencies (refer to figure 4).

Reduction of Closure Costs

The Morro do Ouro ARD program has been able to considerably reduce costs associated with closure. The Morro do Ouro tailings dams ponds occupy 1,553 ha together, this corresponds to 62 % of the overall area to be closed. Considering that the closure test trials installed at Santo Antonio tailings facility - SATF (refer to item 02) indicate the possibility of reducing the cover thickness from 3 to 2.0 m, this means 23.8MUS$ of closure cost savings. If this is applied to Eustaquio (under current evaluation), the cost savings can be even higher, around 41MUS$. Recent data indicate further potential reduction on cover thickness to just 1.5 m (refer to figure 5).

Conclusions

Morro do Ouro site has implemented an ARD management program in the earlier stages of planning to mine its sulphide ores. This approach demonstrates that the ARD and its potential impacts should be considered in the early stages of mine planning and be integrated to site operations and management decisions in order to be successful. The Morro do Ouro ARD program has also demonstrated that although of significant costs, these can be compensated or even surpassed by the benefits arising from the site keeping a good water quality in a sensitive environment very close to the local community and by achieving significant reduction on closure costs.

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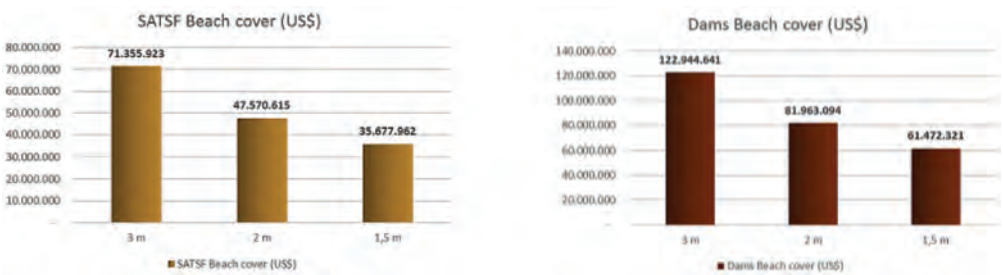

Figure 5 *Closure cost reductions arising from the potential reduction of cover thickness indicated by the test plot at SATSF and total estimated savings for both dams*