Waste Rock Modelling to Improve ARD Prediction and Project Economics: A Case Study

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ABSTRACT

Treatment of mine water impacted by acid rock drainage (ARD) can be a significant cost item for mining projects. Accurate predictions of potentially acid generating (PAG) waste and associated metals are important for estimating project economics, for detailed mine planning, and for developing waste rock management plans to protect downstream water quality. In this study, the methods used to predict ARD are described for an open pit mining project in southern Peru with waste rock containing significant sulfide mineralization. In conjunction with a geochemical testing program, two approaches were used to characterize potentially acid generating waste for the project. The first approach predicted PAG waste based on rock type, and utilized a conservative management strategy to handle all mineralized rock types as PAG, regardless of the variability within each rock type. The second approach used additional waste rock samples and geostatistical evaluation to construct an ARD block model that included an estimate of acid generating potential and contained metals. This allowed for scheduling of waste rock to minimize special handling of PAG materials with an associated reduction in handling cost. The results showed that while the first approach relied on less data, the second approach resulted in cost savings for the project. In addition, relying on rock type alone resulted in some potentially non-acid generating waste being classified as PAG. This case study illustrates the value of geospatial modeling of acid-generation potential to support project planning. The improved economics for the project compensated for the additional cost of the second approach.

Keywords: Acid rock drainage prediction, mine waste geochemistry, block modeling

INTRODUCTION

The Corani project is a proposed silver-lead-zinc project owned by Bear Creek Mining Company (BCMC) and is located in a high-altitude region of southern Peru. Initial feasibility work completed in 2010/2011 projected that the open pit would produce 256 million tonnes of waste rock over an 18-year mine life with waste rock being placed in several dump locations and as pit-backfill. A significant portion of the waste rock will contain sulfide mineralization, and as a result, mitigation of potential acid rock drainage from the waste facilities is a concern for the project. Additionally, naturally-occurring ARD, from weathering of exposed sulfide-bearing formations, and ARD, from historic mining, impact the project area.

Accurate prediction of geochemical risk is important for any project facing potential ARD risk and has implications for project economics, permitting, mine planning and environmental management. Guidelines for testing procedures and the approach to geochemical characterization are given in the Global Acid Rock Drainage (GARD) Guide (INAP, 2009) and several ASTM standards (i.e. ASTM E1915-11 (2011) and ASTM D5744-07e1, (2007)), but the amount of data collected and how this data is integrated into the mine plan and economic model varies between projects and depends on the stage of the project, the type and level of geochemical risk and the regulations and permitting requirements for the project.

In order to better understand the ARD potential of the proposed project and to develop a program for managing ARD at the project, a preliminary geochemical characterization was completed as part of the feasibility work (Dorey & Breckenridge, 2013). This program included static tests, LECO Furnace total sulfur and total carbon assays, and on-site kinetic cell tests. This was combined with geologic and metallurgical characterization of lithologies and material types. The conclusions from this work included the following:

- The geochemistry of the project will be dominated by certain mineralization types; in particular, mineralized lithic tuff with fine black sulphides (FBS) and mineralized tuff with pyrite and marcasite (PM).
- Whole rock analysis indicated that several metals of environmental and processing concern exist at high levels; synthetic precipitation leaching procedure testing suggested that many of these metals are readily leachable.
- The kinetic tests showed that many waste types were acid generating though the behaviour among certain mineralization types was mixed.

Following this work, additional samples were collected for geochemical testing. In total, static testing was completed on over 400 samples with an additional 200 samples analyzed by LECO Furnace.

Two different approaches were used to assess the geochemical risk of the project. The first approach (*Method 1*) predicted potentially acid generating (PAG) waste based on rock type and utilized a conservative management strategy to handle all mineralized rock types as PAG, regardless of the variability within each rock type. Given the availability of additional samples and optimization work being completed for the project, the second approach (*Method 2*) used an ARD block model that included an estimate of acid generating potential and contained metals. The methods used to calculate the amount of PAG material for the project are described below.

METHODOLOGY

Method 1

The initial geochemical testing program revealed that much of the mineralized material could be considered PAG. Consequently, a conservative approach was used to estimate the amount of PAG material generated by the project. It was assumed that all mineralized tuff material would have acid-generating potential and would be managed using encapsulation. Based on this assumption, all blocks classified as mineralized tuff in the resource model were also classified as PAG. This allows a straight-forward approach to predicting total PAG waste, but does not allow the variability of acid-generation potential to be considered.

The annual PAG and NAG quantities were reported from the mine plan in order to stage the design of the waste storage facilities. The design included selective management of PAG waste, including encapsulation within inert waste and engineered cover zones. The calculations confirmed that enough non-acid generating (NAG) material would be available to line and cover the waste rock storage facilities, and in addition, to provide enough NAG material for construction of the tailings dam and for road construction.

Method 2

Following the collection of the additional geochemical samples, an ARD block model was developed to refine the PAG volume estimate as well as to allow the PAG production schedule to be estimated in conjunction with detailed mine planning. The ability to schedule PAG waste strategically as part of the planning process can allow waste handling and placement scenarios to be optimized. Waste with the highest PAG potential is ideally placed in the central portion of the encapsulation zones where oxygen permeation and precipitation infiltration are less important. In addition it may be possible to mine high ARD potential zones during the dry season and low ARD potential zones during the wet season, minimizing ARD risk from active placement areas. Method 2 also results in a reduction in the predicted total quantity of PAG material that must be managed, and increases the quantity of NAG material available for use as a construction material.

TECHBASE was used for data compilation and analysis of the geochemical data. TECHBASE is a database management program that includes capabilities for statistical analysis, spatial modelling and generating advanced graphics. The geochemical data, drillhole collars and survey data were loaded into the database along with the project block model.

Since samples varied in length, samples were composited into intervals with a minimum length of 1 and a maximum length of 8 meters. Once the geochemical samples were composited, composited intervals were assigned a lithology and geometallurgical type from the block model. This was accomplished by using nearest neighbour to assign lithology values from the block model to composite intervals in TECHBASE. Since there is 100% overlap between the block model and the geochemical samples, a maximum of 1 data point was used to estimate each point.

In order to estimate geochemical parameters from the geochemical samples to each block in the model, data was subset by lithology (mineralized tuff or non-mineralized tuff) and variograms were created for each parameter. Strong trends were not evident in the directional variograms so models were only fit to global variograms. In addition, the variograms revealed that for most parameters, spatial trends were only evident to about 75-150 meters.

Based on the variogram models, each parameter was estimated for each block in the block model using kriging. The result is an estimate of geochemical properties for each block in the resource model.

RESULTS

The Corani waste rock exhibits highly inconsistent geochemical behaviour. As indicated above, the initial geochemical test work showed a large degree of variability in acid generating potential, composition, and leachability of contained metals. These conclusions were confirmed by the additional static testing following the initial test work. Table 1 reports the summary statistics for net neutralizing potential (NNP) and metals of concern for both the entire sample database and for each mineralization type.

Table 1 Summary statistics for the sample database for all mineralized samples and by mineralization type (362 samples).

Group	NNP				Arsenic (ppm)				Cadmium (ppm)				Mercury (ppm)			
	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
All-362*	-66	99	-469	-4	286	554	13	5560	15	47	0.02	569	1.07	1.84	0.01	18.80
FBS-116	-33	50	-288	-5	206	478	15	3910	22	64	0.02	569	0.67	1.22	0.01	7.70
FEO3-37	-63	90	-397	-7	312	927	15	5560	5	13	0.15	79	1.52	3.30	0.01	18.80
FEO4-81	-158	142	-469	-4	281	489	13	3150	12	46	0.02	412	1.83	1.85	0.05	6.50
MNO-6	-226	75	-284	-86	644	312	293	1155	28	24	3.86	68	3.07	1.35	1.23	4.76
PM-106	-25	20	-101	-11	378	541	18	4280	15	39	0.17	277	0.69	1.51	0.01	10.60
QSB-16	-48	90	-376	-13	98	119	24	491	2	2	0.05	7	0.81	1.05	0.07	4.43

Table 2 Summary statistics for the sample database for all non-mineralized samples (64 samples).

Group	NNP				Arsenic (ppm)				Cadmium (ppm)				Mercury (ppm)			
	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
Non-Min	-9	16	-93	-3	36	24	10	188	0	1	0.02	4	0.04	0.08	0.01	0.42

The table indicates that most of the mineralization types have average NNPs that exceed the generally accepted criteria for determining likely acid generating waste (an NNP less than -20). However, the range shows that some samples, even in the most likely acid generating mineralization types have NNPs in the uncertain range (NNP between -20 and 20). MnO was the only waste type to show consistent potentially acid generating behaviour based on ABA results. The whole rock analysis results also show a high degree of variability as indicated by the results presented for arsenic, mercury, and cadmium.

Based on the *Method 1* approach, the open pit will produce an estimated 129 million tonnes of PAG material. Using the *Method 2* approach, it is estimated that only 81 million tonnes of PAG material will be produced. *Method 2* also provides an estimate of contained metals for each block.

Figure 1 shows boxplots of selected metals for the sample database and for the block model using *Method 2*. The close symmetry between the boxplots from the sample database and the block model suggest that the estimation processes did not introduce significant bias.

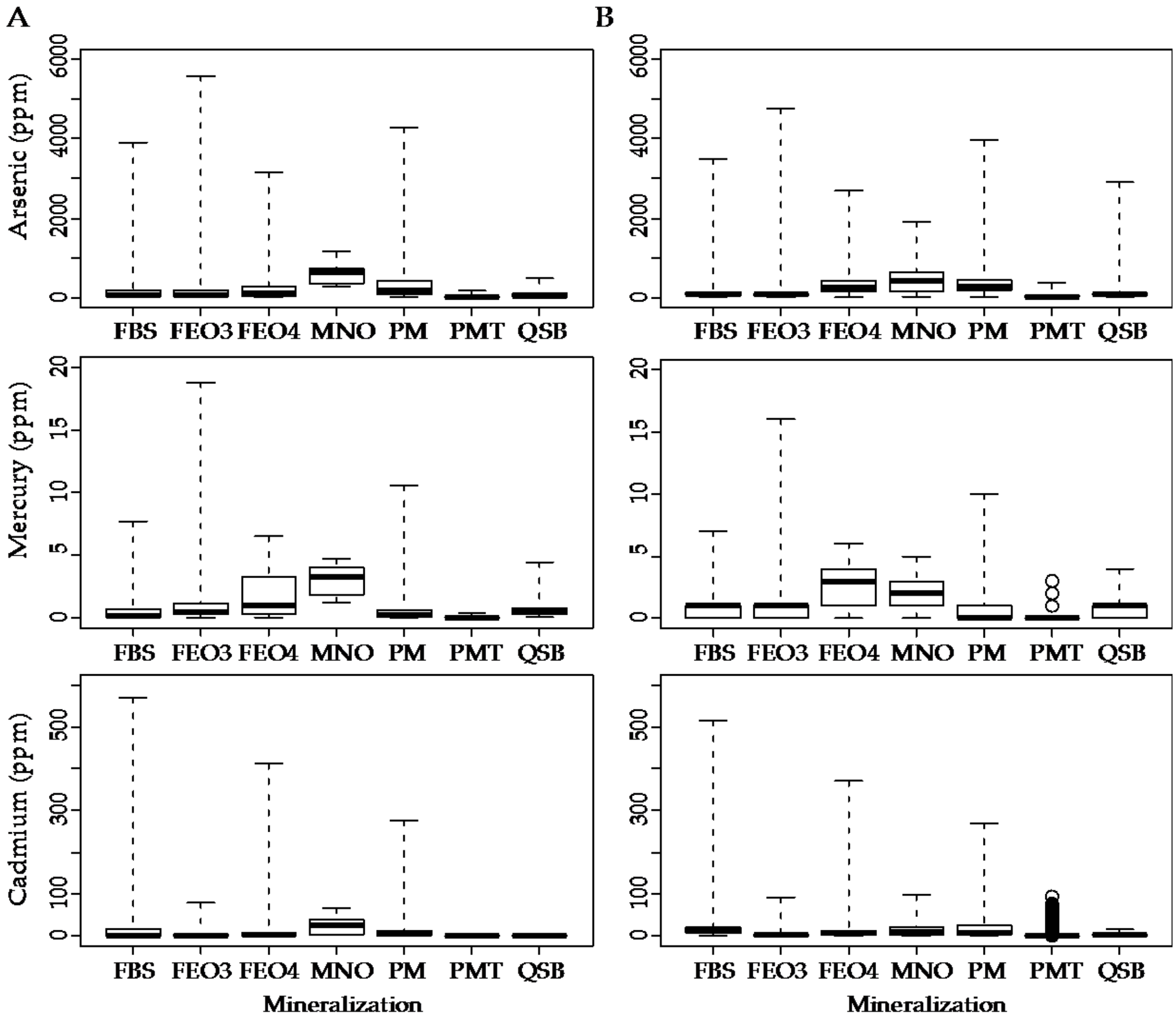

Figure 1 Box plots of selected metals by mineralization type for (A) the sample database and (B) the block model

Figure 2 is a typical cross-section through the Corani pit showing predicted net neutralizing potential using both methods. The mineralization of the section is also shown.

A significant portion of material previously classified as PAG using *Method 1* is classified as NAG using *Method 2*. In addition to an improvement in the outlook for the amount of PAG material requiring special handling, *Method 2* provides a spatially detailed description of PAG behaviour and contained metals. For instance, there are two areas in the cross-section with clearly elevated acid generating potential (centred near x=315900 and x=316800).

DISCUSSION

As the results indicate, depending on the selected method, the estimated volume and strength of PAG material can vary significantly. Each approach has a unique set of benefits and detractors which must be considered when selecting the appropriate approach to ARD prediction. The pros and cons of each approach are outlined in Table 2.

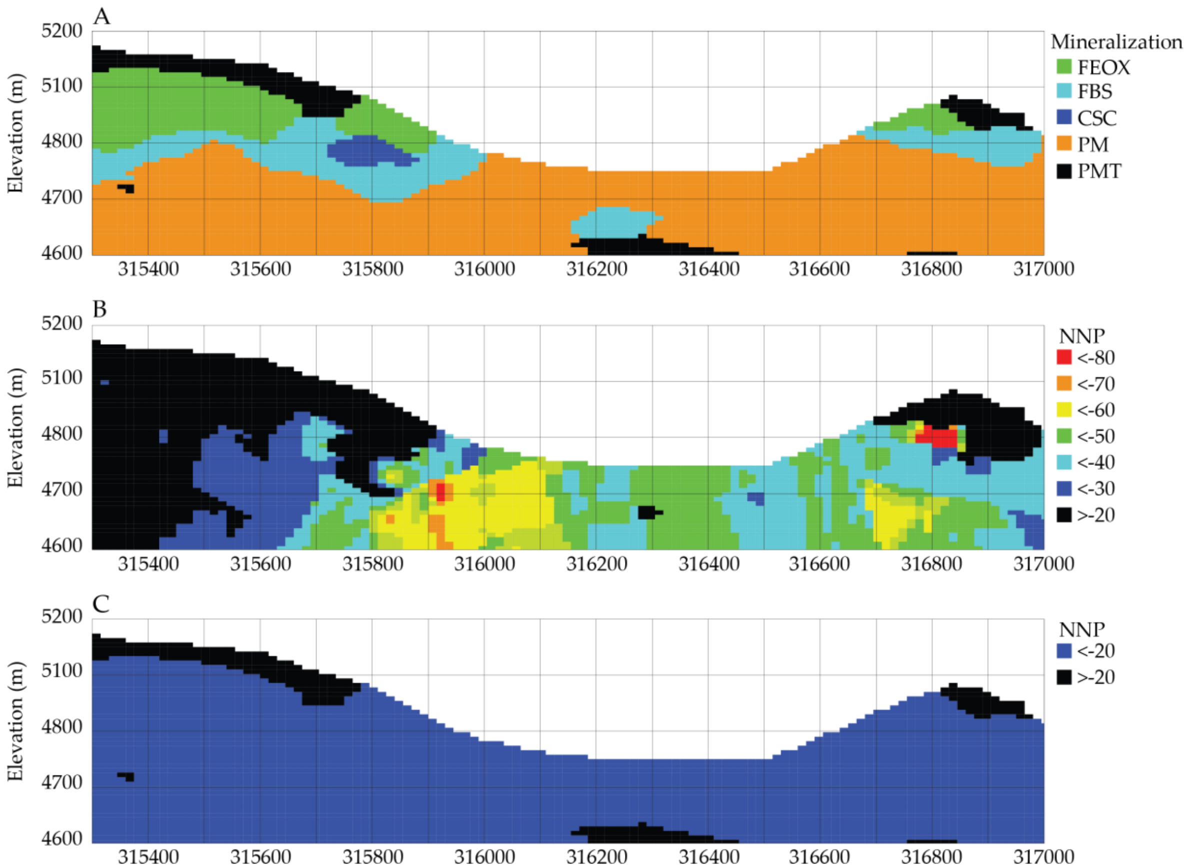

Figure 2 Typical cross-sections through the block model showing (A) mineralization (B) net neutralizing potential predicted using Method 1 and (B) net neutralizing potential predicted using Method 2. Mineralization types include iron oxide (FEOX), fine black sulfide (FBS), coarse sulfide and celadonite (CSC), pyrite marcasite (PM), and post mineral tuff (PMT-non-mineralized material).

Method 1 provides a less detailed prediction of PAG material characteristics. However, this approach relies on less data and is conservative in terms of cost and long-term treatment requirements. This method is appropriate during early stages of project development or for projects where testing of the waste rock indicates consistent acid-generating behaviour.

Method 2 introduces spatial detail to ARD prediction which can be used to refine several aspects of the mine plan. Most significantly, there are several opportunities to use this information to refine the economics of the project. Since the Corani project includes a waste encapsulation and pit backfill plan for managing PAG material, the refinement in PAG volume estimates allows for optimization in where mineralized material will be placed. For instance, if mineralized material is determined to be NAG, it may be placed in the least costly location rather than being transported to the pit or the dump where waste encapsulation is occurring. In addition, estimates of contained metals can be used to refine the estimate of smelter penalties. It appears that some mineralization types contain lower amounts of some metals than others and therefore, it would be appropriate to assume that these may incur lower smelter penalties. *Method 2* is best applied in cases where acid generating potential is spatially variable or there is a need to refine the waste handling plan to improve project economics or to optimize waste handling procedures.

Table 2 Pros and Cons of two approaches for ARD prediction.

Method	Pro	Con
1	• Requires fewer samples • Straight-forward • Conservative	• Less detailed description of ARD hazard • May produce an overly conservative cost for treatment and processing • Cannot be used to optimize waste handling practices
2	• Includes spatial detail in ARD estimate • Can be used to optimize mine plan, processing and waste handling • Addition of detail may improve project economics	• Uncertainty is introduced from the block model • Requires more samples

The most conservative management practice for handling waste rock at a project is to classify all mineralized waste rock as potentially acid generating for purposes of basic engineering. The estimates generated using *Method 2* can then be used to refine the waste handling procedures and improve environmental conditions in detailed design and operations. Using the ARD block model, additional precautions can be taken for the waste that appears to be the most strongly acid generating. For instance, it can be placed during the dry season or more strongly encapsulated. Similarly, the same approach can be used for waste rock with large contents of arsenic or other elements of concern. This has the potential to lessen the impacts to surface water and/or reduce long-term treatment requirements.

CONCLUSIONS

Both methods considered here have strengths and weaknesses. The first method relies on a smaller sample database, is conservative, straight-forward to apply and is based on the conservative management practice of considering all mineralized material to be acid-generating. The second method requires more data but has the potential to improve project economics and optimize waste handling. The selection of the appropriate method depends on the stage of the project, the ARD risk associated with the project and the project management philosophy along with several other factors. A detailed ARD model is not only useful for environmental management, but also can be a tool in mine and process scheduling. As with all components of the mine plan, the ARD management approach should be re-evaluated and evolve along with the project. A management strategy selected during scoping is not necessarily appropriate for feasibility or final planning.

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REFERENCES

ASTM D5744-07e1. (2007). Standard Test Method for Laboratory Weathering of Solid Materials Using a Humidity Cell. American Socitey of Testing and Materials.

ASTM E1915-09. (2009). Standard Test Method for Analysis of Metal Bearing Ores and Related Materials for Carbon, Sulfur, and Acid-Base Characteristics. American Society for Testing and Materials.

Dorey, R. and Breckenridge, L. (2013) Mine Waste Geochemistry Assessment, Corani Project, Puno, Peru. In A. Brown, L. Figuero, & C. Wolkersdorfer (Ed.), *Annual International Mine Water Association Conference – Reliable Mine Water Technology*, vol. 1, pp. 331-337.

The International Network for Acid Prevention (INAP). (2009) Global Acid Rock Drainage Guide (GARD Guide).http://www.gardguide.com/