Mine Waste Geochemistry Assessment, Corani Project, Puno, Peru

Robert Dorey[1], Larry Breckenridge[2]

[1]Global Resource Engineering and Dorey & Associates, rdorey@attglobal.net
[2]Global Resource Engineering, LTD, 7000 S. Yosemite St., Suite 201, Centennial, Colorado 80112, USA
lbreckenridge@global-resource-eng.com

Abstract The Corani project is located in southeastern Peru at elevations ranging from 4800 m to 5200 m. The open pit mining will produce approximately 256 Mt of waste rock, a significant portion of which will contain sulfide mineralization. A geochemical test program was performed on the waste rock to be mined. Static testing of waste rock showed neutralizing potential at essentially zero. Acid-Base-Accounting (ABA) testing was augmented using a LECO furnace. Kinetic testing using a barrel test method was performed. The results of the testing programs were used to prescribe mine waste management methods for the project.

Keywords Mine waste geochemistry, kinetic cells, static testing, acid rock drainage

Introduction

The Corani Project is a base metal and silver mine development project owned by Bear Creek Mining Company (BCMC). Surface water analyses show widespread acid rock drainage (ARD) conditions from two primary sources: naturally-occurring sulfide oxidation resulting from surficial formations high in sulfide, and sulfide oxidation augmented by prior mining activities. In summary, three different water quality groups are present in the project area:

- Clean water up-gradient from mineralized areas with a circumneutral pH (≈ 6.2), total dissolved solids of <10 mg/L, low alkalinity (≈ 3 mg/L $CaCO_3$) and low dissolved metals concentrations.
- Naturally-occurring ARD with a pH at 4.2, TDS of 29 mg/L and slightly elevated dissolved metals concentrations (aluminum, cadmium, lead)
- ARD from historic areas of mining disturbance with an acidic pH (≈ 2.5), high TDS at 3180 mg/L (mostly from 2170 mg/L of sulfate),high total acidity at 2100 mg/L, and elevated levels of arsenic, lead, zinc, and cadmium.

All streams that drain the project site have water quality similar to, or more acidic than, the ARD conditions of the "naturally-occurring ARD" described above. The geochemical waste characterization program was designed on the premise that sulfide oxidation will continue to occur and would require specific management techniques for mine wastes throughout the mine's life cycle.

Methods

The approach to the geochemistry characterization is based on the following industry-standard references, recommendations, and guidelines:

- The Global Acid Rock Drainage (GARD) Guide ;
- ASTM E1915-09 : Standard Test Methods for Analysis of Metal Bearing Ores and Related Materials for Carbon, Sulfur, and Acid-Base Characteristics ; and
- ASTM D5744: Standard Test Method for Laboratory Weathering of Solid Materials

Using a Humidity Cell

It is important to note that these guidelines recognize there is a high amount of variability in conditions from site to site, and therefore, there is no globally prescribed approach outlined in the guidelines. Rather, the guidelines encourage careful site by site consideration that gives the required flexibility to combine various tools and available data to adequately characterize a site — there is no one standard that can be applied. Fig. 1 shows a flow chart of the geochemical characterization approach that is based upon and closely follows the GARD Guidelines.

Geochemical Characterization of Waste Rock

The ore reserve modeling for the project defined several Geological and Metallurgical Types (GeoMet types). The following defines the types and gives the percentage of total waste rock in parentheses. The most important include: PM: mineralized lithic tuff with pyrite and marcasite (18 %); FBS: lithic tuff with fine black sulfides (25 %): PMT: post-mineral lithic tuff (41 %); FeO: oxidized PM or FBS (11 %): QSB: a quartzite/barite-based mineral (2 %); PG: Plumbogummite, a lead phosphate mineral (2 %). The Pre-Feasibility Study (PFS) for the project contained a screening-level geochemical characterization (23 samples) of the waste rock and confirmed that portions of the waste rock was Potentially Acid Generating (PAG). During the Feasibility Level Study (FLS),23 static tests (ABA, SPLP, Whole Rock), 194 LECO Furnace total sulfur and total carbon analyses and, 23 on-site kinetic cell tests were performed. Most of the PMT is removed in the early years of mining as this barren, non-mineralized overburden material is stripped prior to the development of the resource. The proportions of waste by GeoMet type are important to the waste characterization as specific types (FBS and PM) will dominate the geochemistry of the mine waste rock piles.

Static Results

Acid Base Accounting (ABA) indicator tests provide a simple assessment of the waste characteristics and based on industry standards for the neutralizing potential to acid generating potential (NP:AP) ratio and net neutralizing potential (NNP) values provide some measure of the potential geochemical behavior of the waste. The ABA results show that the PM and FBS and PG contain up to 4.5, 2.1 and 0.2 % sulfide sulfur, respectively, while the remaining GeoMet types have relatively low sulfide sulfur

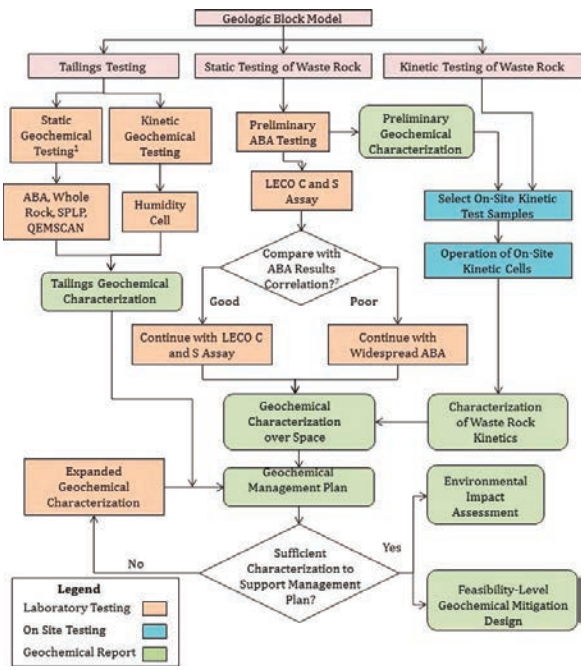

Fig. 1 *Geochemical Characterization Approach*

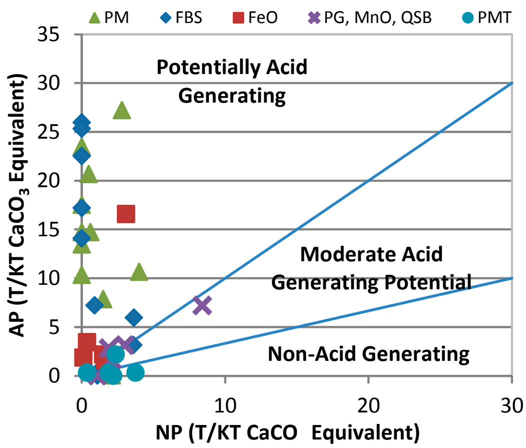

***Fig. 2** Waste Rock Acid-Base Accounting*

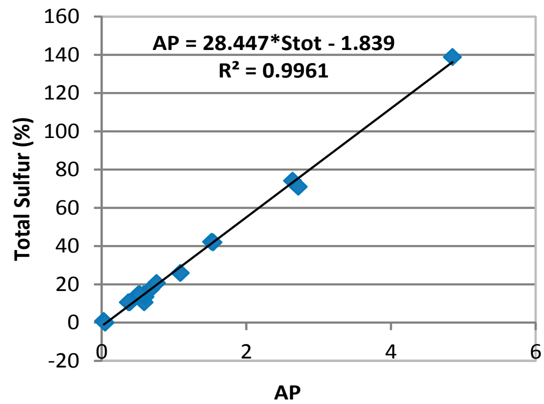

***Fig. 3** AP to LECO Calibration (PM*

values. Universally, all GeoMet types are bereft of NP, and where present, are assigned to clay minerals with availability only at low pH values. Fig. 2 shows the combined ABA results on a scatter plot, based on acid generating potential and GeoMet type. Throughout the development of the management plan it has been assumed that all GeoMet types, with the exception of PMT, have zero NP and are PAG.

LECO Carbon and Sulfur Assays

ASTM E1915-09 states: "In the absence of sulfate forms of sulfur, total sulfur may be used to estimate the sulfide sulfur concentration." The acid potential (AP) in the Corani Mine waste samples comes primarily from the oxidation of pyrite and other metal sulfides. As a result, an approach was adopted using total sulfur as a substitute for acid potential and by correlating total sulfur to sulfide sulfur by comparing ABA data to total sulfur data. Total sulfur (total S) analyses do not account for the effects of barite ($BaSO_4$) which reports as total sulfur in the LECO furnace results, but does not contribute to AP. Analysis results for barium and barite contained in the various waste rock types show that relatively high levels of barite exist in the MnO (0.1 % as S), PG (0.12 % as S), FeO (up to 0.2 % as S), QSB (0.1 % as S) and FBS (0.1 % as S). With the exception of the FBS waste rock, which forms 25 % of the overall waste rock tonnages, the remaining waste rock types comprise a relatively minor quantity of the waste rock produced (+/- 7 %). Although the barite content is recognized to result in a conservative overestimate of the total sulfur, and thereby the AP values, application of a correction for barite would not significantly change the assessment of the PAG characteristics of these waste rock types or the total quantity of material indicated to be PAG. Fig. 3 shows an example of the calibration of Total S *vs.* ABA data for the PM GeoMet type. R^2 values for PM, FBS and the remaining GeoMet types are 0.99. 0.99 and 0.90 respectively, suggesting that an accurate prediction of AP can be developed from Total S LECO data with the application of a calibration equation (see PM equation in Fig. 3).

Whole Rock Analysis (WRA)

The results of the WRA show many metals at above crustal averages, typical for epithermal mineralized deposits. While many metals existed above crustal averages, the key leachable metals that could become present with respect to ARD generation at Corani are: As, Cd, Cu, Pb, Ni, Hg and Zn. The FBS and PM GeoMet type have consistently elevated As levels. Elevated Cd levels exist, particularly in the FBS GeoMet group. Cu is present at levels of up to 500 ppm. The concentrations of Pb in the rock samples show widespread lead mineralization with measured levels reaching 10,000 ppm associated with the lead sulfides in the PM and FBS and as plumbogummite in the PG GeoMet types. Similarly, Zn occurrence, related to sphalerite, reaches levels similar to Pb, particularly in the PM and FSB GeoMet types.

Synthetic Precipitation Leaching Procedure (SPLP)

The SPLP was performed to assess the readily available leachable metals in comparison to the WRA contained levels. Elevated levels of dissolved metals are present in the majority of the leachates. However, the leachability of the PM and FBS GeoMet types shows the highest levels. These results confirm that water and waste management will be critical for the waste rock dumps.

On-Site Kinetic Cells

The decision to perform on-site kinetic cell tests of the waste rock was made due to the unique site conditions at Corani that cannot be replicated in a laboratory environment. The on-site testing allowed for the samples to be exposed to ambient climate conditions, varieties and concentrations of catalyzing microorganisms that are site-specific and to test larger sample particles. The climate at Corani is defined by the project’s high elevation which creates high evaporation rates (in excess of 2000 mm/a) and unique humidity and wind conditions. Snow, ice, and rain fall intermittently through the year with higher precipitation in the wet season. Freezing conditions occur almost on all nights. Laboratory cells cannot duplicate how this unique climate condition may impact ARD kinetics. Recent studies of cold climate effects on ARD also show that the kinetics is significantly slower than expected under laboratory conditions (Sartz 2011). The presence of bacterial catalysts greatly changes the kinetics of ARD reactions. Surface area is also a significant factor in reaction kinetics. The ASTM-standard laboratory humidity cell requires a sample be crushed to less than ¼ inch size. In the ASTM guidelines, however, it states that:

> *“Caution: Recent laboratory-weathering studies of run-of mine waste rock from metal mines demonstrate that crushing bulk sample so it passes the 0.25 inch screen may change the character of the sample by artificially increasing the liberation and consequent surface areas of acid producing and acid-consuming minerals.”*

For this reason, the choice was made to use large particle size material in the on-site kinetic cells.

Kinetic Cell Test Procedures

Samples of the various waste rock types were obtained from drill core stored at the project. The initial steps in sample selection were based on the identification of waste types from borehole logs, photographs, and geological cross sections. The number of samples of each rock type was selected based upon the percentage of the projected quantity of waste rock predicted by the mine model for the pits with a weighting of the number of samples to the higher quantity rock types. Where possible, a range of sulfide contents representative of the individual waste rock type was selected. Samples did not cross lithologic boundaries and no blending or mixing of the samples was performed. A subsample of each sample selected for kinetic testing was subsequently subjected to static testing. The samples consisted of the equivalent of a core box. Core was broken into sections with a maximum individual core length of 100mm and all fines and intermediate particles were included in the test. No crushing or additional material preparation was performed.

Barrel Tests

The test apparatus consisted of 20 L (5.5 gal) plastic barrels fitted with a sampling tube. Initially, each sampling tube was fitted with a sampling valve; however, these tended to freeze overnight and were removed and replaced with a gravity drainage system. Once the core was placed in the barrel, an initial wetting of the sample was performed by sprinkling 5 L of water over the surface of the core. The water was obtained from residual snow banks in and around the project and from snow melt runoff from areas outside of the known mineralized zone related to the project. After the introduction of the water, the water was allowed to drain from the core and collected. Testing of this sample for pH, dissolved oxygen, oxidation-reduction potential (ORP), conductivity and temperature was performed and formed the baseline for comparison with future samples. The barrels were not covered and were left exposed to direct precipitation. On a weekly basis each barrel was inspected. Prior to the inspection, the ambient air temperature at the test site was measured and recorded and the barrel checked for free moisture. Free moisture drained from the barrel was tested for temperature, field pH, dissolved oxygen and conductivity using portable meters. Additional observations were recorded as to whether there was a characteristic odor associated with acid generation/sulfide oxidation emanating from the barrel, whether there was formation of salts/crystals on the barrel surface, and whether the barrel was warmer or colder than the ambient air temperature. In the event that odor, salts/crystals and elevated temperature were measured, the procedure used to obtain a water sample during setup of the barrels was performed. The samples were filtered and tested for field parameters, and a solution sample was collected for laboratory testing. Based upon the field tests parameters, all barrels which showed one or more of the following were selected for additional laboratory testing: pH < 5.0, conductivity > 200 µS/cm, decrease in pH < 2 units in 2 weeks, or an increase in conductivity of 50 % in 2 weeks

Two conditions were adopted under which a specific barrel test was terminated. First, if the barrel showed low conductivity (<100 µS/cm) and stable and neutral pH over an annual cycle, the test was terminated. Second, if depressed pH (< 3 standard units) and elevated conductivity (> 1000 µS/cm) was shown the barrel was terminated.

Kinetic Cell Field Results

After more than a year of leaching, FeO, MnO, QSB, and PG samples were resistant to acidification despite a negative NNP in some of these samples. The magnitude of negative NNP appears to be a strong indicator of acidification in FBS and PM samples. All FBS and PM samples with positive NNP values did not produce acidity and samples with an NNP less than -12 all turned acidic. The weekly field readings of water quality parameters indicate that the reaction rates are variable within rock types which makes characterization challenging. Overall, the field parameters indicate that the minor waste rock types (MnO/PG/QSB) are not likely to be acid generating. This is supported by their relatively high NNP values. FeO samples also have relatively high NNP values with the exception of one sample which has relatively slow reaction kinetics. The ABA results show that this sample group has at least one sample with anomalously high AP, and therefore could be a potentially acid generating; however, the potential for this waste rock type to generate acid is not as pervasive or rapid as FBS or PM. On the other end of the spectrum, PM is the most consistently acid generating. These samples have the highest overall AP and lowest NNP. This group has a high amount of variability with regards to AP, and there are a few samples in this group that have not turned acidic. This is reflected in their AP values which have the greatest range of AP results and a large number of outliers. However, this waste rock type seems to be a consistent acid generator. The FBS sample shows mixed behavior. While none of the samples immediately turned acidic, there are some that are showing signs of ARD. These samples had a lower NNP than the PM samples which is reflected in the slower reaction kinetics of these samples.

Kinetic Cell Laboratory Results

In addition to the field parameters, samples were collected from most of the cells on a monthly schedule and were sent for laboratory analysis. Most metals were elevated in the PM and FBS cells that are acid generating. From the kinetic cell data, it is clear that metals leaching will occur, especially for PM and FBS rock types. The behavior of metals in the FeO cells is variable. There were no significant issues for PG and MnO rock types except for lead and iron which were elevated in most samples. This is a result of the stable pH observed for these cells. The QSB rock type had no issues.

Waste Management Procedures (WMPs)

The waste rock characterization has provided an extensive understanding of the geochemical behavior of the various waste rock types to be mined. This understanding has led to the adoption of specific waste management procedures for the waste rock, mineralized material left in the pit walls, and, from the related tailings characterization, for the projects tailings management facility. Provision of a rigorous surface water management system is an intrinsic part of the operational phases and closure/post closure management of the mine. Separation of “contact” from “non-contact” water and the consumptive use of the water in the process circuit will be performed with zero discharge of contact water. Long-term water treatment has also been included in the feasibility study to manage closure and post closure water sources. The geochemical prediction of long-term water quality following closure and water treatment requirements has been made possible based on the data generated by the characterization work. Also, intrinsic to the WMPs is the conservative assumption that all waste rock containing mineralization should be treated as PAG material. Considering the mining will result in a mixture of the mineralized materials, this assumption was deemed to be appropriate. The mine plan has been tailored to produce non-mineralized (PMT) and PAG materials at a ratio and on a schedule sufficient to allow the placement of PMT in the waste rock dumps concurrent with PAG material to create a buffer zone on the floor, walls and, ultimately, the top of the dump as a cover. These zones will also drain shallow seepage from natural ground and groundwater emerging beneath the dump for collection. Segregation of the waste rock types will also be performed to consolidate all PAG waste rock in a single dump and the remaining PMT not used for the buffer zone will be placed in a separate, non-PAG dump. During operation of the mine the rate of material placement in the waste rock dump is such that increases in the waste rock’s water content is not sufficient to reach the field moisture content at which percolation and leachate generation will occur. All contact water leaving the dump as seepage from the toe of the dump will be collected for consumptive use or for treatment. Placement of the final surface cover will be performed to create an evapotranspiration cover that is designed to reduce flux of precipitation into the dump to deminimis levels.

Acknowledgements

The authors thank Bear Creek Mining Company for support in publishing this work.

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.

INAP (2009) Global Acid Rock Drainage Guide. International Network on Acid Prevention.

Sartz L (2011) Weathering of Waste Rock in Differenct Climatic Conditions-A Kinetic Freeze/Thaw Humidity Cell Experiment. International Mine Water Association Congress. Aachen, Germany.