APPLICATION OF GEO-ENVIRONMENTAL MODELS TO ACCELERATED EIA AND PERMITTING PROCESSES FOR AN ANDEAN PORPHYRY Cu-Au DEPOSIT[1]

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Abstract. Current conditions in the global mining community have dramatically accelerated the quest for bringing projects on line with commensurate pressures being placed on every aspect of the permitting and planning processes. At the same time, the new realities of global communication, coupled with heightened environmental and social awareness, have placed local populations and special interest groups in much stronger positions to participate in those processes. In addition, governments and lending institutions are steadily becoming more sophisticated with respect to environmental and social liabilities while simultaneously wanting to encourage economic development. These competitive and frequently antagonistic interests create a need for efficiency, transparency and clarity in the permitting process and proactive approaches by mining companies.

This paper focuses on a Peruvian porphyry Cu-Au deposit with early social issues that prevented access to the property and existing samples needed for waste rock characterization. The EIA application process threatened to stall for lack of related environmental data. The principals of geo-environmental models were used to assimilate published data from analogous deposits in British Columbia and to create a defensible surrogate database to supplement the yet-inadequate site-specific data. Presentation of such estimates provided a mechanism to proceed with the permitting processes until local social and political issues could be resolved and appropriate environmental data collected.

Water quality data from several mines, as presented in the Red Chris, British Columbia project application for Environmental Assessment Certificate, is included, along with interpretations derived from equilibrium-based modeling. The information is used to substantiate and justify the choice of surrogate water quality parameters for acidic drainage from the Peruvian property in question. The surrogate composition was taken to temporarily represent dump seepage and sulfidic wall rock runoff and to estimate facility effluent and pit lake quality.

Geo-environmental modeling principals are shown to be useful for advance planning and proactive environmental planning, including situations where the permitting process has outpaced the availability of critical environmental data. Resulting data can be shown to be pragmatic and robust, less subject to interpretation than some other assumptions, as well as independent of the specific operator making the application.

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Introduction

Favorable commodity prices, especially since 2004, and following a period of poor economic conditions for the mining industry, have resulted in rapid expansions into developing countries and an urgency to bring new mines on line. Simultaneously, local environmental and social awareness, facilitated and amplified by readily available global communications, has imposed restrictions on that expansion in some cases. This is especially true where examples of modern mining practices and social impacts are readily apparent to locals.

Local resistance to, and/or expectations of benefits from, new mining operations can lead to access limitations, increased security risks, permitting difficulties, and general delays. These potential points of conflict are exacerbated when very aggressive, and sometimes unrealistic, developmental schedules have been proposed. Environmental studies are especially subject to compromise in this environment because of their dependence on site access, sample availability, and long-term monitoring of field conditions and sometimes long-term laboratory testing (e.g., kinetic studies).

While the authors do not advocate the subversion or dilution of environmental protection to accommodate developmental schedules, we recognize the benefits of a pragmatic approach that can fairly anticipated environmental risks while deferring certain confirmatory laboratory programs and proceeding with studies of other issues.

The application of the principals of geo-environmental models (GEMs) can provide defensible surrogate data and predictions of environmental consequences in the absence of adequate site-specific data. The application of GEMs may be better understood as “analogue ore deposit-based environmental predictions” (ADEP). Resultant surrogate data can be used to sustain environmental impact assessment (EIA) applications that have become stalled for lack of data or to focus and streamline an upcoming investigation. Similarly, actual data derived from multiple operating mines in similar climates can add credibility to predictions based on laboratory data interpretations.

Background

This paper discusses the use of GEMs, or ADEP, to the permitting process for a porphyry Cu-Au deposit in Peru. Although several previous attempts to develop the property had generated much geologic information and a wealth of subsurface samples, data for characterizing waste rock and predicting long-term water quality were largely absent. Samples of existing core and cuttings were required, and new core was desirable, for the traditional laboratory analyses required for prediction of pit lake water quality, waste rock dump seepage quality, and water treatment options. However, sample acquisition had become stalled, and thus the permitting process compromised, by social pressures that restricted access to existing cores and new drilling.

As a means of allowing the overall permitting process to advance while social issues were being resolved, a supplement approach was introduced that incorporated environmental data from existing and closed mines that have exploited very similar ore deposits in similar climates. Specifically the data were used to anticipate waste rock drainage quality and the effectiveness of lime additions to treat effluents. This supplemental approach was presented to the Peruvian Ministry of Energy and Mines (MEM). In this way, a successful submittal of an EIA was made possible, with its acceptance pending acquisition of site-specific data as appropriate samples became available.

The ore deposit of concern is an Au-rich, calc-alkaline porphyry Cu with abundant magnetite in the continuum described by Sillitoe (2000) (Type 20c of Cox and Singer, 1986). The host stock is intruded into a sedimentary sequence containing thick limestones. Although no significant skarns are known, Pb- and Zn-bearing mantos are common in the intruded limestones. It is located at about 3,500 meters elevation and receives approximately 1.36 meters of precipitation annually with an average temperature of 7.4^{o} C.

Geo-Environmental Models

The history of GEMs and the application of ADEP can be traced to the U.S. Geological Survey and the investigations of the Summitville Mine in Colorado following its abandonment and the subsequent environmental calamity (Plumlee and Nash (1995) and Plumlee et al. (1995). GEMs build upon the classification of mineral deposits in Cox and Singer (1986) and go on to incorporate the typical environmental signatures of those deposits. As an example of the most obvious application, the distribution and abundance of pyrite of a particular deposit type translates into the tendency for that deposit to create acid rock drainage. Similarly, the mineralogy and major, minor, and trace metals common to a deposit type help to anticipate the characteristics of seepage from weathering waste rock.

GEMs go farther, however, and incorporate aspects of mining, milling, beneficiation, and recovery methods typically associated with particular ore deposit types and/or commodity. Knowledge of these associations allows anticipation of environmental issues (e.g., deep mine drainage, pit lakes, tailings impoundments, rock dumps, and slag heaps) and the character of process wastes such as tailings, sludges, waste water, and dust.

"ADEP" is recommended here as an alternative to GEMs because experience has shown that the principle of applying analog ore deposits is more easily grasped by those unfamiliar with the concept. Furthermore, it describes the objective and intention of the application (i.e., environmental prediction).

At present, ADEP is limited by the availability of hard data. Although general characteristics of a given ore deposit type itself are clearly useful for predictions, actual data on waste rock seepage, pit wall runoff, pit lake chemistry, and tailings storage facility seepage are far more useful. The data cited in the next section are highly unusual and enormously beneficial.

Analog Data for Porphyry Cu-Au Deposits

A valuable set of data was assembled as part of the successful application for an environmental assessment certificate for the Red Chris Project in British Columbia (Appendix K, Red Chris Development Co., 2004). Red Chris has been classified as a porphyry Cu-Au deposit using the same criteria discussed above. In addition to extensive environmental baseline monitoring and laboratory testing of waste rock and process waste specific to the Red Chris project, data were gathered from six previously mined porphyry Cu-Au deposits, all in British Columbia. Deposits represented in the database include Island Copper, Kitsault, Huckleberry, Gibraltar, Mount Polly, and an undisclosed deposit identified as "C." The first two are now permanently closed, and the latter three named deposits are operating again after varying periods of closure.

The data collected constitute approximately 600 water analyses, mostly incomplete, representing seeps primarily from waste rock storage areas and one long-term column test over six years in duration (Huckleberry data). Several of these deposits are associated with calcareous host rocks, and active addition of lime (for remediation) is reported to be taking place at another. The geologic variability that clearly exists among the six deposits and their host rocks likely explains much of the observed variability but also provides a valuable demonstration of the impacts of neutralization.

Although far from ideal or complete, the data appear to represent an array of water qualities that one could expect from a reasonably consistent type of ore deposit with various amounts of available acid neutralization in a limited range of environmental conditions (i.e., temperate conditions with marked seasonality and moderate to high rainfall).

Data were presented as tables of analytical values and in the form of pH versus constituent plots, which were reconstituted and embellished for this paper.

Interpretation and Application of Analog Data

Three main requirements of the Peruvian EIA directed the application of GEMs as described in this paper: prediction of waste rock seepage quality; prediction of pit lake water quality; and prediction of waste water treatability. Each of these requirements could be addressed, at least preliminarily, by data in the Red Chris data set. While some of the waters collected from each of the six mines clearly represent classic ARD, characterized by low pH plus elevated SO_4^{-2} and metals, others are circum-neutral pH, typically with significantly lower constituent concentrations. Figures 1 through 4 show the available data for four selected constituents measured in waters from the six British Columbia mine sites, including SO_4^{-2}, Fe, Cu, and Al. Given the presence of limestone associated with some of the deposits and reported application of lime at some operations, the data were considered to define a range of water quality from Cu-Au porphyry deposits bounded by three end-members: unmitigated ARD, neutralized ARD (whether by natural or engineered means), and water unaffected by ARD.

Consequently, the Red Chris data set should include representatives of waters to be expected from the subject deposit and operation, including waste rock dump seepage, with and without additions of lime, runoff from pit walls containing sulfidic rock, and ARD after treatment with lime.

To better define ranges of constituent concentrations that could be expected for each of the three scenarios or end-members, The Geochemist's Workbench (GWB, Bethke, 2004) was used to simulate the process of a hydrated lime ($Ca(OH)_2$) addition to various examples of the low-pH ARD. Figures. 1 through 4 contain lines representing the simulated pH versus concentration evolution of selected constituents (total dissolved S as SO_4^{-2}, Fe, Al, and Cu) and four representative individual ARD waters with the addition of lime in the presence of air ($\log P_{CO2}$ = -3.5 and $\log P_{O2}$ = -23[1]). Simulations were initiated by equilibrating the whole water analysis as

[1] Log P_{O2} = -23 atm. was chosen to constrain calculations to the Eh-pH range observed for natural "environments in contact with the atmosphere" (Fig. 11.2, Garrels and Christ [1965]).

provided with the aforementioned fugacities and allowing for charge balancing, typically by adjusting the sulfate concentration. The resultant solution was then titrated with lime to a pH of approximately 8 to produce the curves appearing on Figs. 1 through 4. During both simulation phases, those mineral phases judged to be unlikely to precipitate were suppressed, leaving schwertmannite, amorphous $Fe(OH)_3$, gibbsite, gypsum, and simple Cu sulfates as the likely solubility-controlling phases.

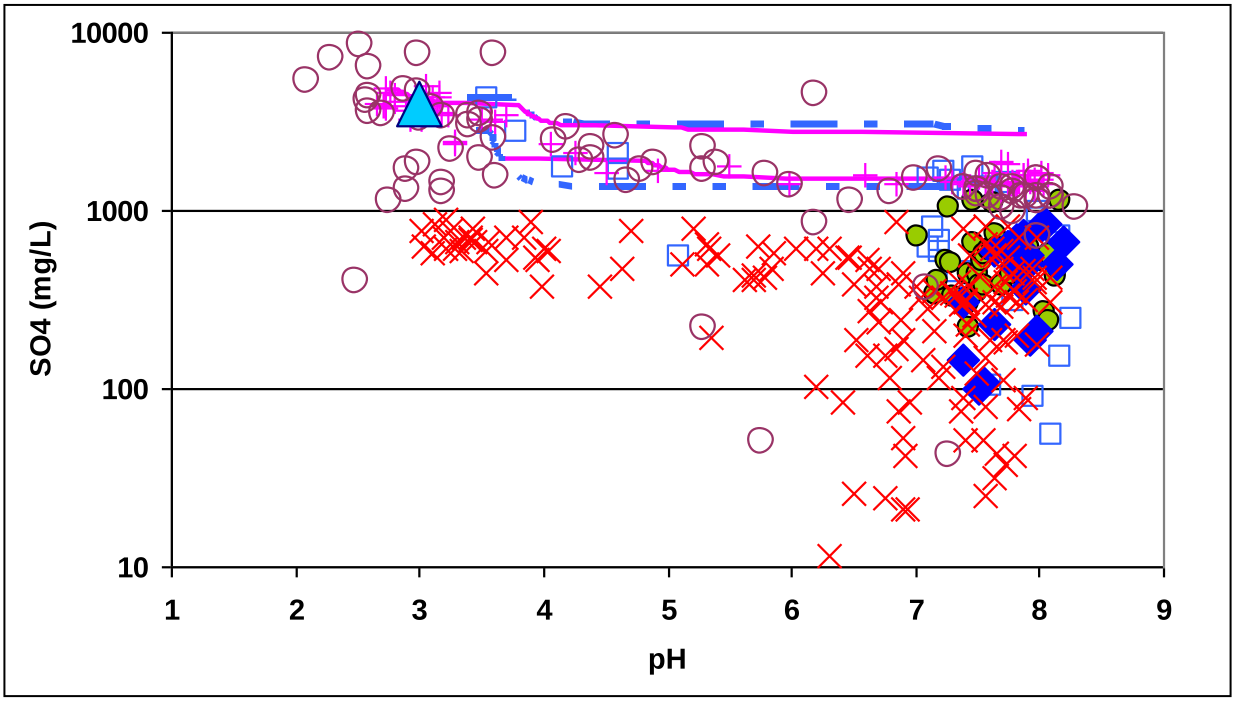

Figure 1. Observed SO_4^{-2} concentrations in porphyry Cu-Au seepage and modeled neutralization curves.[2]

[2] Figs. 1 through 4 – Available water quality data for six porphyry Cu-Au deposits in British Columbia. Deposits include: Island Copper (□), Gibraltar (○), Mount Polly (♦), Huckleberry (+), Kitsault (X), Deposit "C" (▲). Lines represent modeled compositional evolution of selected acidic seepage solutions resulting from added lime. Dashed lines originate from Island copper data and solid lines from Huckleberry humidity cell data. Analyses from other deposits were too incomplete or otherwise unsuitable for modeling. Differences between initial data and starting points of neutralization lines represent adjustment of solution composition by GWB (note dashed arrow on Fig. 3). The single large solid triangle on each plot represents an "average" un-neutralized ARD composition used in EIA predictions (i.e., surrogate waste rock dump seepage and pit wall runoff from sulfidic wall rock).

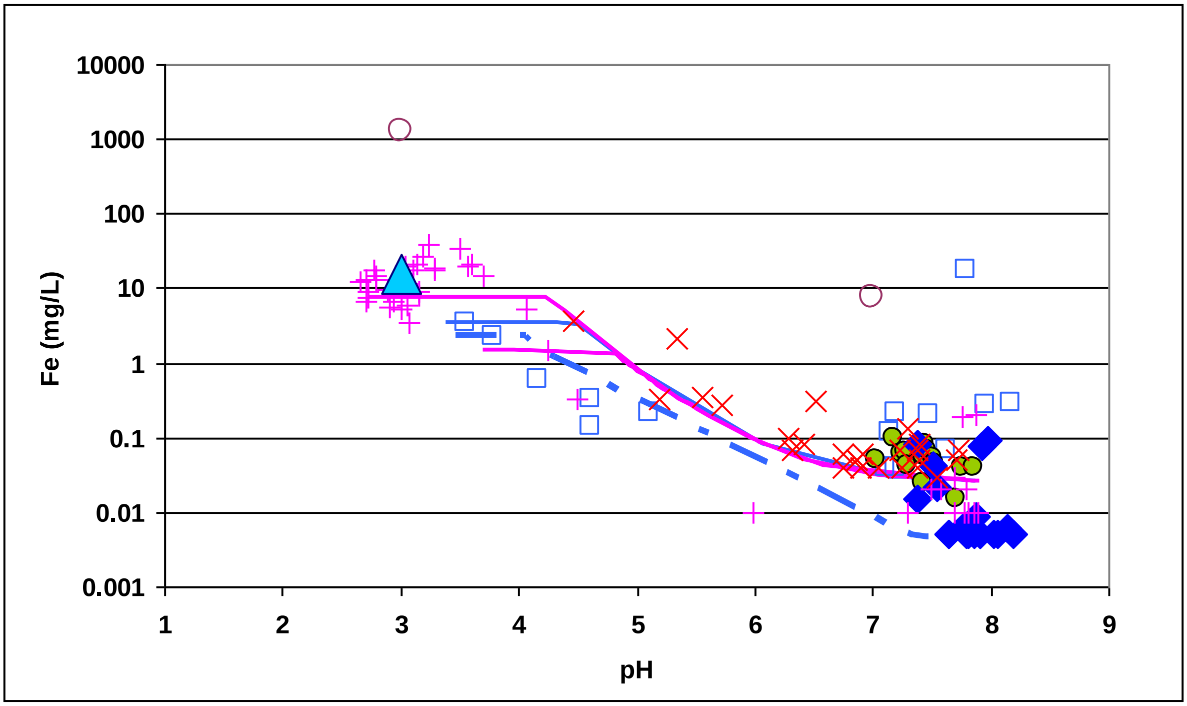

Figure 2. Observed Fe concentrations in porphyry Cu-Au seepage and modeled neutralization curves.[2]

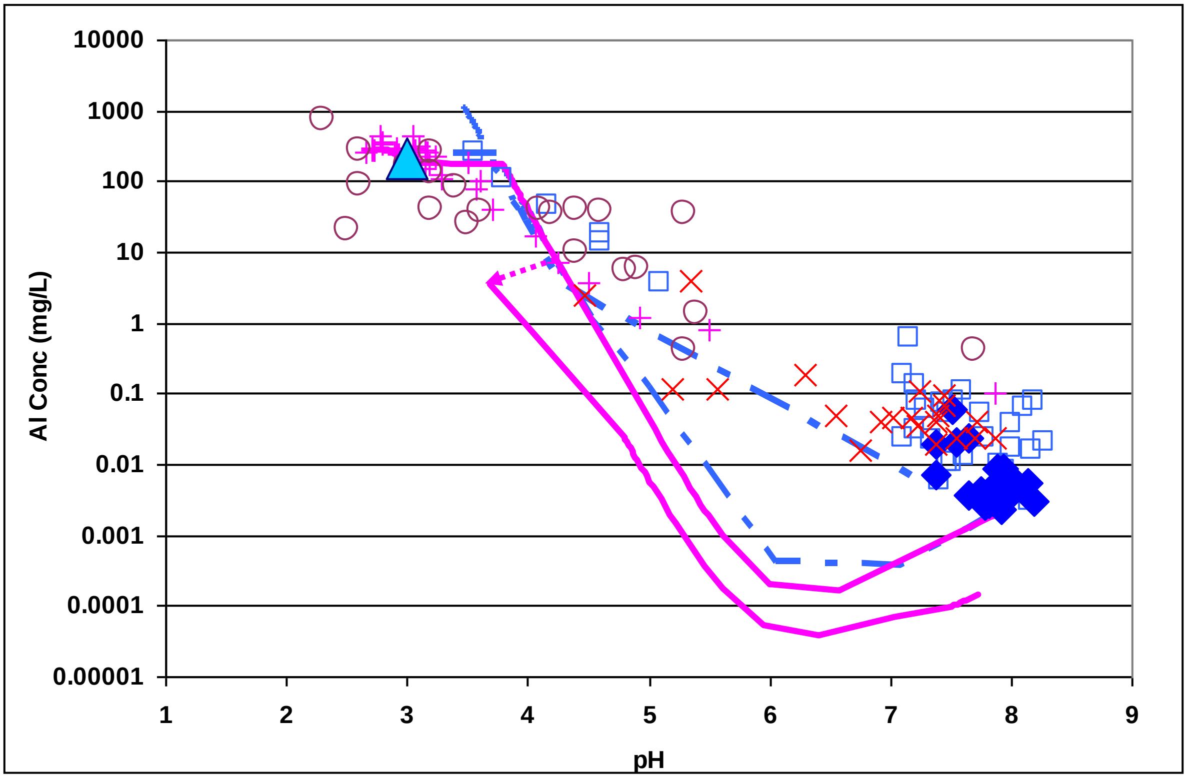

Figure 3. Observed Al concentrations in porphyry Cu-Au seepage and modeled neutralization curves.[2]

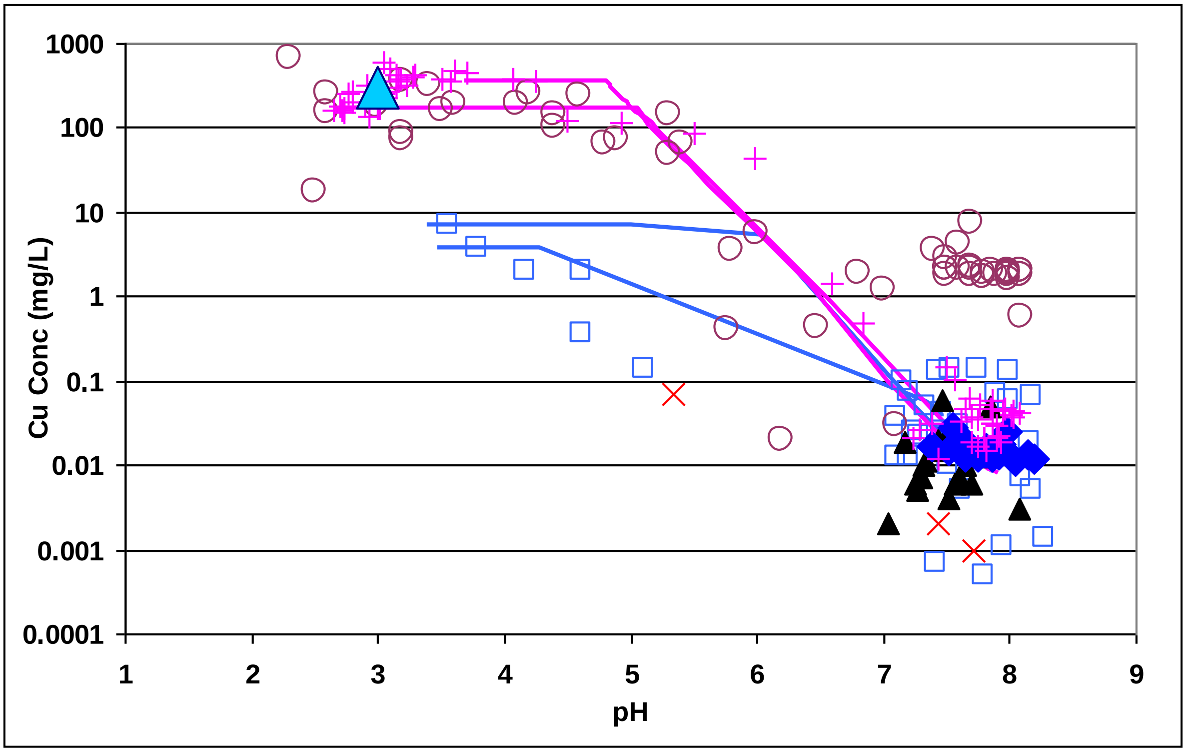

Figure 4. Observed Cu concentrations in porphyry Cu-Au seepage and modeled neutralization curves.[2]

Sulfate (Fig. 1) exhibits a comparatively narrow range of concentrations over the observed pH range. Except for those waters having pH above about 6, SO_4^{-2} concentrations vary no more than one order of magnitude. Gypsum is the primary solubility control for SO_4^{-2} although alunite and schwertmannite are predicted to be saturated at low to intermediate pHs. Lime neutralization curves emulate the natural distribution of SO_4^{-2} concentrations, showing little variation over a wide pH range. Accordingly, the lower concentrations reported above pH 6 seem unlikely to be due to any controlling solid and thus are probably due to simple dilution.

Iron (Fig. 2) and Al (Fig. 3) concentrations exhibit similar bimodal distributions with higher concentrations at low pH (typical of ARD) and significantly reduced (by 3 to 4 order of magnitude) concentrations at high pH, probably resulting from neutralization. Intermediate concentrations and pHs suggest incomplete neutralization processes. Simulated lime neutralization curves reflect minimum solubility of the oxyhydroxides between pH 6 and 8 and predict the observed high pH concentrations as well as bounding the intermediate compositions. In the case of Al, pHs between 6 and 7 likely resulted in concentrations less than detection limits.

The correspondence between modeled neutralization paths and observed data supports the interpretation that intentional lime additions resulted in the observed waste rock effluent Fe and Al chemistry.

Copper (Fig. 4) concentrations also reflect a bimodal distribution, apparently affected by lime neutralization. Especially notable is the agreement between relatively constant observed and modeled Cu concentrations below pH 5. Although lime neutralization of the ARD waters successfully predicts most of the observed high-pH Cu concentrations, a group of high-pH Gibraltar samples appears to be over saturated in Cu and cannot be similarly derived from the observed ARD. It is likely that this group represents a separate source, perhaps with a complexing agent not encountered in the other waters.

Application of the Analog Approach to the EIA Process

In an oral presentation format, the concepts of GEMs and ADEP were presented to MEM representatives followed by a comparison of the deposit to the generic porphyry Cu-Au model. Comparisons were drawn between the deposit in question and the six deposits in British Columbia and the environments of each. The Red Chris data set was then presented as a supplement to the limited site-specific acid-base accounting (ABA) data available at the time. In addition, no kinetic, leachability, or peroxide-accelerated oxidation data were available to allow predictions of waste dump seepage quality or pit wall runoff quality. ADEP was offered as an alternative approach to deriving such data.

Existing ABA data clearly predicted a high potential for ARD formation that would likely resemble the more acidic waters presented in Figs. 1 through 4. Mean concentrations of SO_4^{-2} and metals were chosen from the acidic Red Chris samples and assumed to be representative of unmitigated waste rock dump seepage and sulfidic pit highwall runoff. These concentrations were then used as inputs to mixing and equilibration models designed to predict site discharge water and pit lake water quality.

In addition to predictions of ARD quality, the Red Chris data set was used to support the viability of proposed lime treatment of the site discharge water. It was argued that lime treatment was indeed capable of producing acceptable water quality for discharge into local streams based on the quality of high-pH water in the Red Chris data set and the ability of modeling to predict similar qualities by titrating lime into the initial ARD.

All conclusions drawn from the supplemental approach based on ADEP were offered as preliminary, pending further testing of available core, testing of new core, and initiation of laboratory and onsite kinetic experiments. A program for obtaining the necessary data was outlined, and it was agreed to present the ADEP-based predictions in the EIA application. ADEP was also included as a roadmap for designing the remaining sampling program.

Conclusions

GEMs are generally indispensable for early prediction of environmental issues and liabilities as well as planning environmental investigations. They should find use in any new mining project. This paper relays one such application and highlights the usefulness of GEMs in facilitating the permitting process. In addition, the following are specific conclusions.

1. The application of GEMs and ADEP to environmental predictions is currently limited by the availability of adequate databases. The mining industry should strive to allow the accumulation of such data to support the overall health of the industry.

2. GEMs and ADEP were shown to be an effective approach for moving the EIA process forward in the absence of adequate site-specific, traditional waste characterization data

3. A credible plan to acquire the necessary traditional data will be required as part of the EIA submittal. ADEP is not a substitute for site-specific data.

4. GEMs and ADEP can be effectively used to guide the acquisition of traditional data by defining critical geologic variables and identifying the most important potential environmental impacts.

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