Mine Planning and Acid Rock Management

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ABSTRACT

Mine planners face a number of obstacles to good management of acid generating materials. Too often the consequence of these obstacles is the generation of acid drainage, long-term water treatment, and possibly environmental impact. This paper reviews leading practice approaches to mine waste characterization drawing on the GARD Guide and mine planning from Kinross Gold Corporation's G4 resource characterization approach. Key obstacles to mine waste characterization and planning are discussed and solutions suggested.

Keywords: Mine planning, acid rock, management, characterization, life cycle

INTRODUCTION

Acid mine drainage and the need to manage acid generating materials is a well-documented problem of which mine planners are well aware. Nevertheless success in avoiding acid mine drainage through good management from start to finish of a project is mixed. Mine planners face a number of obstacles to good management of these materials, which this paper will discuss.

Mine planning is used in this paper to indicate the task of converting resources to economic reserves. This is a complex task that includes a large amount of information of variable detail and accuracy. The information includes metal content, processing costs, capital requirements, metallurgical properties, geotechnical characteristics, hydrogeological characteristics, as well as geochemical properties, etc. Mine planners are generally judged on their ability to optimize the economic value of a mineral deposit to allow the company to evaluate the overall feasibility of proceeding with a project. This task is often associated with very tight time schedules that require quick decision-making, in many cases with incomplete data or interpretations.

This paper explores the obstacles that mine planners face in developing good management strategies for acid generating materials. It focuses on the following three aspects:

- Incomplete geochemical characterization
- Integration of geochemical characterization into mine planning
- Long-term ARD management

Leading practice approaches will be identified as well as the obstacles faced by the mine planner to implement these practices. Recommendations will be made of how the practices can be improved.

LEADING PRACTICE

GARD Guide

Much has been written on the topic of geochemical characterization during the mine life-cycle. The Global Acid Rock Drainage Guide (GARD Guide, www.gardguide.com) provides a description of ARD characterization and prediction techniques (in Chapters 4 and 5) that can be used in developing the information required for mine planning and evaluation. A phased assessment approach is promoted that provides sufficient data at all stages of the mine life-cycle (exploration, pre-feasibility, feasibility, construction, operation, closure and post closure). Leading practice environmental management requires that the potential for acid drainage be identified early in the mine life-cycle. The overall characterization aims to identify the distribution and variability of key geochemical parameters, including sulfur content, acid neutralizing capacity and elemental composition and their influence on acid generation and element leaching.

The components of the characterization include (the information below draws on the GARD Guide, refer to it for more details):

- Sample selection from each geological material that will be mined and exposed and from each waste type. Selection of representative samples should consider material type, spatial representation, compositional representation, and focused vs. random sampling. Standard operating procedures should be developed for the geological logging and the collection and documentation of sample selection. The GARD Guide recommends that the number of samples depends on the amount of disturbance, the compositional variability within each material type and the statistical degree of confidence that is required for the assessment.

- Laboratory and field testing to characterize the acid generating and metal leaching potential of mine materials, including static and kinetic tests:
  - Static tests:
    - Chemical composition (whole rock and elemental analysis)
    - Mineralogical analysis
    - Acid base accounting (ABA)
    - Net acid generation (NAG)
    - Water extraction (batch extraction) tests with solution assay
  - Kinetic tests:
    - Humidity cell leach testing
    - Column leach testing
    - Field column or rock pile testing to obtain information about material reactivity under ambient site conditions

The results from these tests, together with climatic, hydrologic, and hydrogeologic information for the site, provide a basis for predicting the potential for acid generation and metals leaching. With this information mine plans, including management strategies and environmental impact assessment, can be developed. This geochemical characterization process is depicted in Figure 1 from the GARD Guide (Figure 5.5).

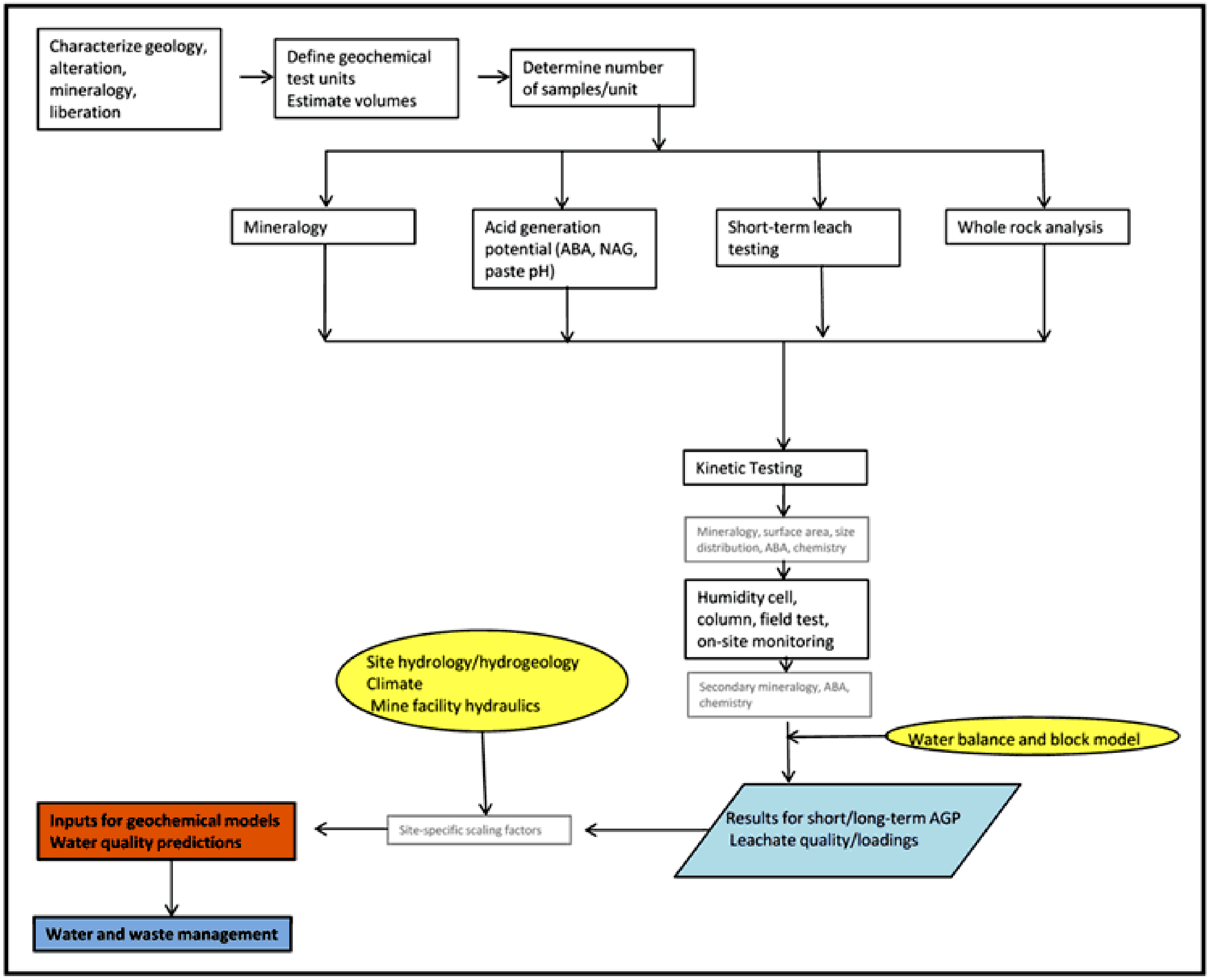

Figure 1 Geochemical Characterization Program

Kinross G4 Approach

An example of how geochemical information can be considered in mine planning is Kinross Gold Corporation's (KGC) in-house system for resource modeling referred to as G4 (Sims, 2014). Resource modeling using G4 draws from a database that includes four components:

- Geologic (G1)
- Geochemical (G2)
- Geometallurgical (G3)
- Geotechnical (G4)

Detailed correlation analysis is used to assess the 'G' components and populate the resource model with key variables. These variables; in addition to density, grade, and process characteristics; include elemental characteristics, acid base accounting, and hydrogeologic information. Scorecards are used to measure the maturity of all data bases with respect to project maturity. Target Maturity stages are:

- Initial Project Setup

- Initial Drilling
- Infill Drilling
- Scoping Study
- Pre-Feasibility Study
- Feasibility Study
- Operations

Figure 2 illustrates how the G4 feeds into the Resource Block Model and Mine Optimization

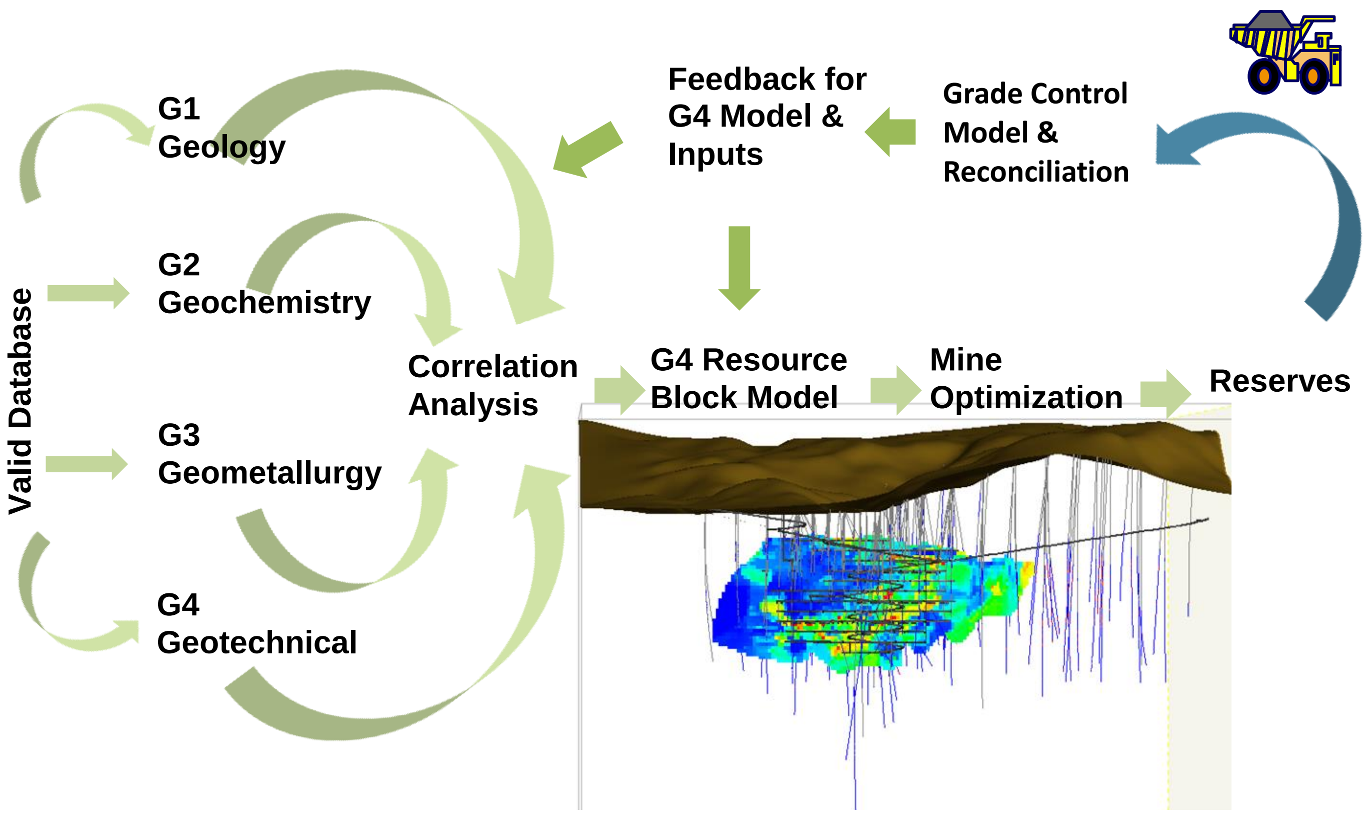

Figure 2 KGC G4 Process for Developing Resource Block Model and Mine Optimization

THE MINE PLANNER'S DILEMMA

INADEQUATE GEOCHEMICAL CHARACTERIZATION

Good management of acid generating materials often begins with initial geochemical characterization efforts. Geochemical characterization is a typical component of baseline studies and factored into mining plans, impact assessment and permitting. Unfortunately too often geochemical characterization begins when an orebody is determined to be economic. At this point in mine feasibility planning, time is money and the pressure to obtain necessary approvals is high. Because sampling, analysis, interpretation and reporting require time, there is a tendency to manage the scope of characterization efforts to stay on schedule. While statistical analysis of test results is advisable to confirm that a representative data set has been obtained, this may be ignored in deference to pre-established schedules.

Additionally, kinetic testing is required to assess the relative rates of acid generation and metals leaching reactions and to provide information on the evolution of potential acid drainage over time. Because kinetic testing requires time, and time is often in short supply, the mine planner or project team may feel considerable pressure to limit the extent or duration of kinetic testing.

These obstacles can of course be overcome. Sulfur analysis should begin with initial exploration and should be performed on all samples analyzed for target elements. As the geology of a mineral target becomes known, static testing of representative samples from each material type should be performed. Additional static testing, kinetic testing and water quality characterization should follow. With an early start and progressively expanded, it is possible to characterize geologic materials and develop appropriate management strategies for inclusion in mine plans without delay to feasibility and project development schedules.

Acid base accounting (ABA) evaluates the acid generation potential of the various geologic units present at a site. As part of ABA, the bulk quantities of acid generating minerals (e.g., sulfide minerals) and acid neutralizing minerals (e.g., carbonate minerals) are measured to assess whether the materials tested will have sufficient capacity to neutralize the acid potential, or if the materials have the potential to generate acidity. Acid generation potential is commonly interpreted by the ratio of neutralizing potential over acid generating potential (NP/AP) or NPR ratio. Unfortunately, all-too-often, there are geologic units that are quite geochemically variable. In addition, because geochemical weathering rates are dependent upon oxygen, water and temperature, the timeframes for the onset of acid drainage can be quite delayed or difficult to estimate. The mine planner, confronted with these unknowns, is challenged to select the “right” management approach or even, in some cases, to understand if there is a “real” problem.

Of course it can be argued that the mine planner should always exercise the “precautionary principle” when it comes to potential acid rock management, but that is in many cases an overly simplistic, costly, and conservative approach. Support from environmental and geochemical advisors is recommended to ensure that management requirements for various geochemical domains are understood and incorporated into the mine plan.

Because few ore bodies are fully characterized prior to mine development, ultimate geochemistry and mine planning options may not be fully understood. In too many cases, following initial permitting and approvals, ongoing monitoring of geochemical characteristics of wastes is not continued. Further, changes in geochemical domains within the same geologic unit are common, and the need for expanded geochemical characterization, are often not recognized. Failure to recognize these changes can result in the construction of acid generating dumps, tailings facilities, or use of acid generating materials for construction, roads, etc. In the end, mitigation of the consequences of failure to recognize these types of changes can be time consuming, costly, and damaging to the social license of a company.

To reduce the potential that the mine planner is working with inadequate information, geochemical characterization efforts need to continue as the ore body continues to be developed. Plans must include procedures to recognize new geochemical domains and the requirement for more extensive characterization to ensure that these materials are properly recognized and managed.

Integration of characterization in mine planning

Possibly an even more significant obstacle is that geochemistry is commonly not fully integrated into block models. Acid generating potential must be correlated with geology type to create geochemical domains. This information is input to the block model along with metallurgical, geotechnical, and hydrogeological information. At the end of the day, the mine planner is working with a very complex data set. Failure to achieve strong correlations with geology type or to fully understand the potential for acid generation and the management options available can result in the mine planner deciding to ignore the data, as "it is not clear what it means".

The mine planner should be provided support by a geochemist to ensure that initial characterization is well done and correlations with geology are strong. Additional support may also be appropriate to ensure that management strategies for different geochemical domains are well conceived.

As mine plans develop and more information becomes available regarding recovery, grade, geochemistry, etc., mine planners and operators seek management solutions that have minimal impacts on reserve estimate and economic performance. Mine planners are judged on their ability to convert resource to economic reserves and this unfortunately may mean that issues, especially where the impacts are not clear or will only manifest over time, may not be entirely addressed. This focus on positive results can mean that more environmentally acceptable options may not be fully considered as they would mean lower reserve estimates and lower short-term economics. For mines with relatively long lives, e.g. greater than 15 years, the economic tradeoff between avoidance or isolation of potentially acid generating materials and ultimate treatment of acid drainage often favors the selection of water treatment as the preferred alternative.

Corporate policies on full-cost analysis and environmental protection are required in order to limit the potential for this obstacle to result in unacceptable environmental performance. Corporate environmental departments along with independent reviewers of block models and mine plans must be diligent and engaged. More recently, capital approval systems (CAS) which have been adopted by many companies, include more detailed outlines of what is required at each evaluation step, from scoping through feasibility studies, helping ensure that the correct environmental parameters are collected.

Another obstacle, hinted to previously, is that geochemistry and acid rock management are typically not core competence areas for the mine planner. Due to the unique knowledge requirements, planning and management input is typically provided by outside experts who may not fully understand the geotechnical, metallurgical, or economic factors that are critical for planning. The planner's ability to incorporate this information into the mine plan will vary by individual and level of experience. Clearly the ability of geochemical and environmental advisors to understand what is involved in mine planning and to support the mine planning process can be invaluable. Environmental advisors must have a good understanding of the management practices available and the ability to effectively communicate with the mine planning team.

DISCUSSION

Responsible acid rock management involves a host of leading practices of which mine planning, highlighted in this paper, is an important consideration. It is essential that obstacles to responsible acid rock management be identified and overcome. Because many of the obstacles involve the availability of data and its interpretation, it is critical that data base maturity be clearly defined for all stages of project maturity. Table 1 provides a general summary of critical analyses relative to project maturity/life cycle.

Table 1. Critical geochemical analyses related to project life cycle

Data or Analysis	**Lead**	**Initial**	**Infill**	**Scoping**	**PFS**	**FS**	**Ops**
Design/review of data collection strategy (selection of analytical method and sampling density and distribution)	Expl	●	➡	➡	➡	➡	➡
Total sulphur and carbon	Expl	◔	●	➡	➡	➡	➡
Multi-element data	Expl	◔	●	➡	➡	➡	➡
ABA, NAG, water extraction	Expl/ Env		◑	●	➡	➡	➡
Kinetic Investigations	Env		◔	◕	●	➡	➡
Identification of materials management requirements	Env/M-Planner		◔	◑	◕	●	➡
Monitoring data collection strategy (sampling frequency, distribution, analysis)	Env/M-Planner						●

Progressively more detailed/advanced

Full implementation

Use/maintain/update as necessary

The mine planner cannot be expected to solve the mine waste characterization and management dilemmas described above alone. Geochemical and environmental advisors must provide support and assistance to the mine planning process including the identification of management options, costs and their expected effectiveness. Strategies for more effective planning for acid generating materials should include:

- Statistical analysis and other modelling to integrate basic geochemical information, including a clear understanding of ARD potential, into the overall mine block model. This process may be done in a number of steps of refinement to expedite the overall mine planning process.
- Development of inventories of effective management strategies for various types of ore bodies, acid generating potentials, and climates.
- On-going monitoring of the geochemical behavior of mine materials and the effectiveness of management strategies. Every effort should be made to identify the potential range of uncertainty/variability that may exist. Likewise management strategy performance must be monitored and where necessary updated over the mine life-cycle to maximize the potential for success.

When mine planning is done with a complete set of data, confidence in the results, as required by processes such as NI 43-101, is more likely. When geochemical characterization is not well defined it is suggested that comments be provided to indicate the approach that was used, potential uncertainties and their possible implications. This would provide important information for investors. It is recommended that this be further considered by the ARD community, INAP, and others to support the development of more standardized definition of data and planning requirements for project maturity stages.

CONCLUSION

The mine planner faces a number of obstacles to good management of acid generating materials. Inclusion of ‘screening analyses’, such as total sulphur and carbon in early analysis of drill holes provides a foundation for subsequent static and kinetic testing. As discussed, this information provides a basis for understanding geochemical weathering, management requirements, and potential environmental impact. Begun early in the process, it is possible to minimize or avoid planning and permitting delays.

Data base and management strategies must advance with project maturity stage. Most mining companies have project stage gates, with well described requirements, that must be met before a project can be advanced. Geochemical characterization and management strategies are important components of the stage gate process and must be defined.

Environmental advisors must provide input on management options, costs and their effectiveness. On-going monitoring of management effectiveness is required to recognize problems early and make adjustments as required.

On-going monitoring data collection and interpretation aims to recognize changes in geochemical domains that may require new management strategies. Collaboration between mine planners and environmental personnel is critical to ensure that management strategies are embedded in mine plans and environmental protection requirements are achieved.

ACKNOWLEDGEMENTS

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NOMENCLATURE

ABA	Acid base accounting
ARD	Acid Rock Drainage
Env	Environmental (includes geochemistry)
Expl	Exploration
G4	Kinross Gold Corporation's standard for resource characterization
M-Planner	Mine planner
NAG	Net acid generation potential
NPR	Ratio of neutralizing potential over acid generating potential (NP/AP)

REFERENCES

INAP (International Network for Acid Prevention), 2010 GARD Guide

Sims, John, 2014 Kinross Standards for Resource Characterization – G4, Version 1.4