Predicting Water Quality at Hardrock Mines

Methods and Models, Uncertainties, and State-of-the-Art

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FOREWORD

The prediction of water quality at mine sites, the focus of this report, is a challenging topic because of its technical complication and inherent uncertainties. The quantity and characteristics of mine wastes are among the most important determinants of water quality at a mine site. Mine wastes or mined materials include the extraction area (open pit or underground mine), waste rock, unprocessed lean ore, heap or dump leach piles, tailings, and metallurgical processing wastes, although all of these wastes may not be present at a specific operation. The quantity of material generated can be very large, with mine waste areas covering hundreds of acres and amassing to tens or hundreds of million tons. The quality of mine waste drainage can be environmentally innocuous, circumneutral to basic with elevated concentrations of metals and oxyanions, or highly acidic with very high heavy metal concentrations. In addition to the potentially large physical size of mine waste disposal facilities, these materials remain on the ground long after mining and processing operations cease and can generate problematic drainage for centuries. Thus, in the absence of remediation, mine wastes are potentially sources of contaminants that may be transported from the mine site and adversely impact environmental or human receptors for many years.

Mine waste characterization techniques, in conjunction with geochemical and physical modeling and relevant existing data, have been applied to predict the quality of drainage that will be generated by mine wastes over time. These predictions are intended to contribute substantially to the fundamental information required to design and cost remediation that will allow compliance with water quality standards in a technically and economically efficient manner. Designing remediation measures in advance of mining allows their costs to be factored into the economics of mineral resource recovery, and for environmental mine waste management measures to be integrated effectively into the mine plan. Whereas this concept is fairly simple, the prediction of mine waste drainage quality over time can be a difficult proposition.

Factors that complicate drainage quality prediction range in scale from small to large. First, on a small scale, drainage quality is influenced by the dissolution of minerals present in the mine wastes, as well as secondary reactions among solutes, gas phases, and solid surfaces. The mineral surface areas available for reaction can be difficult to quantify, and the rates of reaction in a complex system are not well known. Second, on the large scale, geology, climate, methods of mining and mineral processing, and mine waste management approaches vary among and within operations. Variability of these large-scale factors means that characterization problems and results can be unique to an operation or operational component, and this limits the degree to which information from one site can be applied to another. Third, extrapolation from laboratory to operational scale must address complicating factors such as differences in particle size, environmental conditions, water and gas transport, and how these variables affect drainage quality over periods of decades or centuries. There is virtually no available information describing the effect of variables such as these on well characterized operational mine wastes over extended periods of time. The lack of this field information introduces uncertainty into predictions, and this uncertainty must be accounted for. Finally, characterization results and subsequent modeling must lead to environmental mine waste management programs that are practical and verifiable in the field. Given the large masses of material often moved in mining operations, this consideration is far from trivial.

Despite these difficulties, geochemical characterization techniques can provide predictive information on mine waste drainage quality that is beneficial to the environmentally sound management of mine wastes. Given the complexity of long-term predictions and the associated uncertainty, mine waste characterization should be viewed in the context of a program, integrating results from a variety of characterization techniques over time, rather than a single test or a one-time series of tests. This program begins with testing in the exploration phase and extends through closure and post-closure in the form of monitoring. Technical expertise from those experienced in the field will most likely be required to develop and apply a well-designed waste characterization program.

This report identifies various techniques for the geochemical characterization of mine wastes, including conventional geochemical and mineralogical analyses, static tests, short-term dissolution tests, and
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kinetic tests. For each technique, the report addresses advantages and limitations and sources of uncertainty, and makes concise recommendations for improvements. Sources of uncertainty in characterization and modeling identified in this report can be used to evaluate mine characterization and management plans. The characterization flow chart presented in the report provides a strategy that can be used at a wide variety of mine sites and recognizes that the specific characterization techniques can vary among these sites. Collection of an adequate suite of samples for testing is also discussed, and is a cornerstone for a reliable characterization program.

The application of characterization techniques during various phases of mineral resource development (exploration, development, active mining, and reclamation, closure, and post-closure) is discussed in this report. A modeling approach including development of a conceptual model, input data collection (including characterization results), model selection, sensitivity analysis, and evaluation of results is presented. The information presented in this report addresses many of the challenges associated with predicting water quality at mine sites noted above and will be useful to regulators, mine operators, and the public who are involved in mine waste characterization and modeling projects.

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