

Project Title: Predictive Environmental Studies of Sulfide Oxidation Processes

Statement of Problem

In the Western US, open pit and underground mining is leaving a legacy of pit lakes and acid mine drainage across the landscape. In some cases, water-rock interaction between mineralized wallrock and inflowing lake waters creates lakes with low pH and high concentrations of trace metals. Quantitative, predictive models for the evolution of pit water chemistry through time are required for Environmental Impact Statements (EIS), and are necessary for biological risk assessments for these lakes. The paucity of kinetic information for phases other than pyrite leads to inaccurate predictions, as illustrated in the study of the Getchell pit lake (Tempel et al., 2000). Here, the authors were forced to use pyrite dissolution rates as a proxy for dissolution of orpiment and realgar (As sulfide phases). As a result, their model overpredicted As concentrations in lake surface water by more than 10X. Data and rate models produced by this project will begin to fill the gaps in the database on sulfide oxidation, and lead to more accurate predictions of pitlake water quality in the future. Similarly, predictions of the rates of sulfide oxidation and acid production in acid mine drainage are limited by a paucity of laboratory experimental studies. In particular, there is very little data for rates of oxidation of sphalerite, chalcopyrite, and arsenian pyrite. These minerals are increasingly recognized as important contributors of potentially toxic elements to the environment due to the great abundance of polymetallic sulfide veins and mantos, and porphyry copper deposits in the U.S. Microbial oxidation processes are very poorly understood, but clearly enhance oxidation rates. Finally, partitioning of trace and minor constituents of these minerals (Al, Sb, As, Be, Cd, Cr, Mo, Pb, Hg, Mn, Ni, Se, Ag, and Tl) into fluids during surficial oxidation is very poorly known. Typically the residence of these elements in the source mineral (solid-solution, minor or trace mineral inclusion, defect structure, etc.) is not even well known. Only recently have we had available technology (laser and ion microprobes, XAFS, high resolution SEM, etc.) to evaluate the distribution of elements at the micrometer scale in primary minerals. Now is the time to study the reactivity of these minerals and their trace element contents and develop a theoretical framework that will allow predictive geochemical reaction models that can help decision makers plan appropriately to minimize or remediate environmental impacts. In addition to mine related environmental problems in the subaerial environment, it is becoming increasingly clear that sulfide oxidation in the coastal marine environment may have important environmental implications. Where mine workings or mine tailings are exposed to marine waters (Ellamar Deposit, Prince William Sound, AK; Phillipines, Vancouver Island, B.C.) different and largely unknown processes can lead to localized acid production and solubilization of potentially toxic elements. In addition, research on the ocean floor has shown significant sulfide deposits that are oxidizing in place. Thus, a small but significant portion of our studies will focus on reactions of sulfide minerals with oxygenated seawater.

Objectives

The objective of our work is to understand and ultimately quantify the behavior and distribution of environmentally significant elements as they are dispersed from their sources through the environment. Sources of elements in mineralized terranes include natural and anthropogenic entities such as ore deposits, mine tailings, and waste rock. Characterization of these source materials involves identifying the solid phases where the toxic elements reside, the speciation of

the toxic elements (e.g., oxidation state and type of bonding to the mineral structure), and the rates and mechanisms of release from the mineral structure. Once released from their sources, physical, inorganic, and biogeochemical processes act to re-distribute and transform both dissolved and particulate forms of the elements. Our specific objective is to determine rates and mechanisms of sulfide mineral oxidation and toxic element release due to chemical and microbiological processes. Laboratory experiments conducted in the last decade have determined the rates of inorganic oxidation of some common sulfide minerals under certain ranges of conditions, but much more needs to be done, especially with alteration of specific minerals and chemical reactions mediated by microorganisms. In addition, little has been done experimentally to determine the behavior of potentially toxic trace elements that exist as intergrown refractory minerals and non-sulfide mineral inclusions (usually silicates or oxides), in discrete inclusions of sulfides or sulfosalts, in defect sites, or in solid-solution within the host minerals. Trace minerals containing toxic elements may have very irregular distribution in the host sulfides. This project will conduct experimental reactions of fully characterized natural sulfide minerals and will be fully integrated and interactive with pertinent Mineral Resource Program field investigations. These data will be incorporated into geochemical reaction models in the form of reaction rates, solid-solution activity coefficients or specific interaction models, distribution coefficients, sorption models, and thermodynamic stability of minor or secondary phases. New fundamental information will be utilized in geochemical and biogeochemical reaction progress calculations for specific field sites to provide a predictive capability of environmental behavior of ore deposits.

Relevance and Impact

This Project will advance the development and application of geoenvironmental mineral deposit models by identifying the processes that control environmental signatures of mineral deposits and the fate of metals in the environment. The proposed studies will support the development of predictive models necessary for future mineral-environmental assessments, and will provide the private sector and government agencies involved in regulatory and stewardship activities with the tools to make informed and rational decisions about (1) land use before exploration and mining and (2) post-mining remediation.

Strategy and Approach

A multidisciplinary research effort involving laboratory, field, and theoretical approaches will be used to predict the environmental behavior of potentially toxic elements and sulfur derived from sulfide mineral deposits. The proposed studies will support the development of predictive models that will provide the private sector and government agencies involved in regulatory and stewardship activities with the tools to make informed and rational decisions about (1) land use before exploration and mining and (2) post-mining remediation. Field oriented studies of the environmental behavior of metallic ore deposits by USGS scientists and others provide the framework and rationale for a concerted effort to improve predictive models of toxic element dissolution and migration. Elements of interest include Al, Sb, As, Be, Cd, Cr, Cu, Fe, Mo, Pb, Hg, Mn, Ni, Se, Ag, Tl, and Zn. Our objective is to determine rates and mechanisms of sulfide mineral oxidation and toxic element release due to chemical and microbiological processes. These studies will provide fundamental information on the location and concentration of trace elements and trace minerals in primary

sulfides, and on the partitioning of elements between primary and secondary solid phases and the aqueous environment during alteration. Improved geochemical and geomicrobiological models will be tested at relevant field sites and will greatly improve our ability to quantify and predict the behavior and fate of potentially toxic elements during degradation of mineral deposits in the surficial environment.

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