Arsenate and chromate attenuation in acid mine drainage systems

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Abstract

The oxidation of iron sulfide minerals in mining environments generates acid mine drainage (AMD), leading to acidic pH waters with relatively high concentrations of potentially toxic elements. The formation of secondary iron minerals, such as ferrihydrite (Fh) and schwertmannite (Sch), plays a critical role in controlling the mobility of these elements. In these environments, iron mineral surfaces are involved in adsorption reactions that mitigate the spread of metals and metalloids. Additionally, the coprecipitation of ions and their incorporation into iron oxides modify the surface properties, affecting their stability and reactivity. Knowledge of the binding behaviour of iron mineral surfaces in AMD is needed to establish the mechanisms of pollution sequestration at the solid-solution interface and to develop remediaton procecures to minimize AMD pollution.

This study investigates the reactivity of iron minerals surfaces in AMD. Batch adsorption experiments were carried out with ferrihydrite, schwertmannite, and goethite in the presence of arsenate or chromate and organic acids. Key factors influencing the reactivity of these AM-formed iron minerals, such as pH, redox conditions, and the presence of co-precipitated species like Al, were examined. By integrating the macroscopic information with microscopic data, surface complexation modeling was used to characterize the ion-binding behavior on these minerals.

Results showed that increasing pH, sulfate concentration or the presence of organic acids enhances the mobility of both arsenate and chromate. This is likely due to changes in surface charge, competition for the binding sites, and the decrease of the anion-exchange reactions with the sulfate groups. On the other hand, the incorporation of Al ions in the mineral structure also leads to an increase on the mobility of these oxyanions, which is caused by changes in the surface area and surface charge, and the alteration of the binding site concentration. These observations were modelled using a surface complexation model, specifically the CD-MUSIC model. The spectroscopic data was used to constrain the surface complexes, e.g. monodentate and bidentate inner-sphere complexes identified as the main complexes for chromate, and monodentate inner-sphere and bidentate outer-sphere complexes selected for sulfate.

A major challenge lies in predicting when these iron minerals will transition into more crystalline forms, as these changes may result in the re-mobilization of adsorbed pollutants, increasing environmental risks. This study enhances the understanding of the physicochemical conditions driving such transformations, contributing to the development of more effective remediation strategies for managing AMD-related pollution.