Schwertmannite formation in acid mine drainage in NE Viet Nam

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The province of Quang Ninh in northeastern Viet Nam is one of the largest coal mining districts of the country, hosting reserves estimated at 10 Gt. The coal is mostly anthracite and is mined both in open pits and underground. This study focuses on acid mine drainage from the Coc Sau open-pit mine near the town of Cam Pha. The mine is approximately 3 km in diameter and has an orange-colored lake in the center, which drains through a tunnel into a creek. After flowing for ~4 km through the densely populated town, the acid mine waters discharge into the ocean.

The drainage waters have a pH of 2.4±0.4, a temperature of 30.3 °C, and an Eh of 0.63±0.02 V under normal conditions, but after major rain storms the pH may be as high as 7.2±0.1, with an associated Eh of 0.29±0.05 V. The low-pH water contains the following major components (in mg/L): Fe = 46±18, SO4$^{2-}$ = 850±100, Al = 7±2, Mg = 76±3, and Ca = 66±18.

The creek bed and the contained pebbles are covered by a bright orange crust. This crust consists primarily of schwertmannite, quartz and sheet silicates (mostly kaolinite and illite) in the outer, highly porous part, whereas the inner part, directly on the substrate, consists of mostly ferrihydrite and sheet silicates. Scanning electron microscopy revealed the typical appearance of schwertmannite, i.e. small (usually <1μm across), spherical to ellipsoidal aggregates resembling sea urchins, and further suggested that schwertmannite also forms crusts on, and is intergrown with, sheet silicates. This suggestion was corroborated by transmission electron microscopy, which has shown that the schwertmannite aggregates in many cases contain a core of sheet silicate. Selected area electron diffraction groups are significantly displaced from bulk positions.

In order to construct an Eh-pH diagram showing the stability fields for schwertmannite and ferrihydrite, we calculated the activity of the major chemical components using the extended Debye-Hückel equation. The ionic strength of the system (I = 0.016 M) was computed from the water conductivity [1]. Based on the available thermodynamic data, including a logK$_{sp}$ value of 1.2±0.5 for schwertmannite with the ideal formula FeO(HO)$_{3.64}$(SO$_4$)$_{1.18}$ [2], a plot of Eh vs. pH was generated showing a schwertmannite field that is consistent with the observed conditions of our low-pH water samples. The diagram also coincides with an Eh-pH diagram constructed with a logK$_{sp}$ of 0.88±0.01 for schwertmannite with the formula corresponding to FeO(HO)$_{2.715}$(SO$_4$)$_{1.113}$ [3].

At present, we do not understand yet, why the innermost part of the crust, directly on the substrate, consists mostly of ferrihydrite.