Elko Roundtable 2012;
Acid rock drainage for engineers and scientists

by Bryan Ulrich and Steve Lange

On March 15, 2012, about 24 attendees from several western states attended Roundtable 2012, hosted by Knight Piésold and Co. at the Red Lion Hotel and Casino in Elko, NV. The focus of this year's discussion was "Acid Rock Drainage for Engineers and Environmental Scientists." Other names may have been more suitable for the event, perhaps combining geochemistry, with air and water quality and their long-term effects on soil and rock mechanics.

Bryan Ulrich (senior vice president, Knight Piésold's Nevada operations) and Steve Lange (senior geochemist, Knight Piésold, Denver, CO), helped facilitate the discussion.

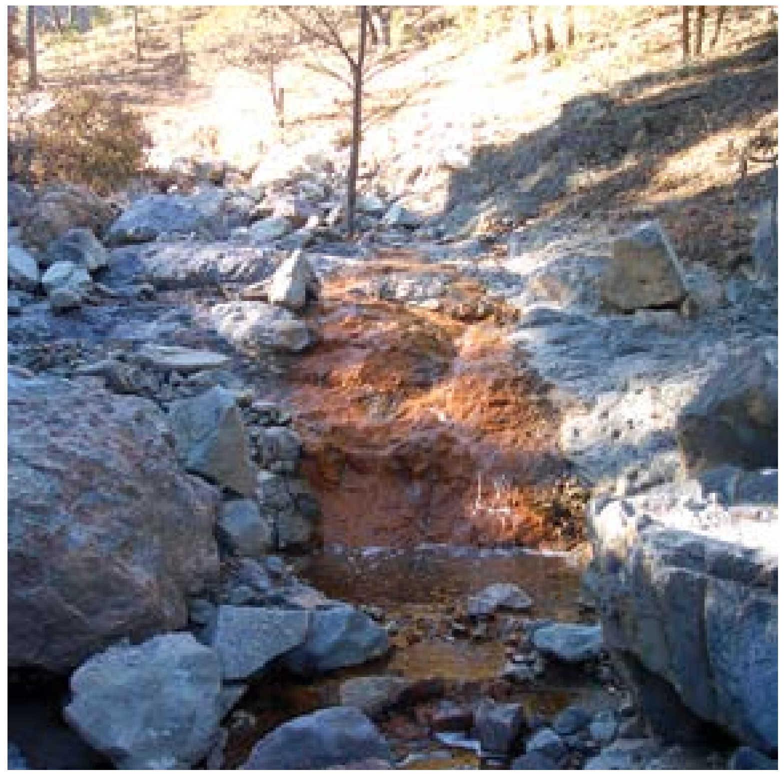
Attendees included personnel from a dozen mining properties, various corporate offices and academia. There were also attendees from a geochemical testing laboratory to help respond to specific questions pertaining to testing protocol and procedures.

The purpose of Roundtable 2012 was to exchange ideas and information pertaining to broad topics revolving around geochemistry, especially as it relates to mine waste. Compared with traditional conferences and symposia, the roundtable type of forum tends to provide a much less inhibited format for discussion. In the roundtable format, lively discussions and applicable tangential departures are encouraged.

This was the seventh in the series of Elko Roundtable events. Previous Roundtables pertained to heap leach pad design, construction and operation; design, construction and operation of tailings storage facilities; site-wide water considerations; mine closure and cover design; strides toward sustainability in mining; and high-density tailings, paste, and filtered tailings.

The initial subtopics for Roundtable 2012 included:

- Safety share.
- Geochemistry: The ARD machine.
- Geochemical testing: A better understanding for engineers.
- Physical changes of materials prone to ARD.
- Nevada experiences.
- Experiences elsewhere.
- Dealing with ARD – Prevention and reduction:
  - Designing for ARD prone materials.
  - Waste rock storage, isolation, segregation, blending.
  - Tailings, wet covers.
  - Strategies for mixing materials.
  - Reuse and treatment of ARD waters.
- Design of closure for ARD.
  - Pit lakes.
  - Perpetual treatment.
- Future developments.



Acid rock drainage at a mine site in Mexico.

The roundtable created a good environment to discuss the current practices, challenges and accomplishments associated with acid rock drainage (ARD). Since there is considerable overlap between the roundtable's subtopics, the conversations frequently wandered from topic to topic and back again. In keeping with the spirit of an open roundtable discussion with unbridled conversation, the authors have chosen to create "sanitized minutes" of the meeting, wherein specific quotes are not generally attributed to their author, but rather the proceedings of the discussions are presented in a stripped-down version in order to avoid stifling the free exchange of ideas. The following is partly a tangential discussion and partly the proceedings of the roundtable.

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Inspecting bedrock exposures.

The day began with a safety share. This year's safety share was a bit out of the ordinary, as it was presented in digital format. The safety share relayed the story of the Sullivan Mine disaster.

In May 2006, four fatalities occurred at the partially reclaimed No. 1 Shaft waste dump at the closed Teck Cominco Sullivan Mine near Kimberley, British Columbia, Canada. The fatalities occurred at the toe of the dump in a seepage monitoring station that was often and recently used without incident. Tragically, one victim after another entered into the monitoring station and fell victim to the toxic levels of air chemistry.

Research following the tragedy indicated that atmospheric changes would either cause the waste rock facility to take in fresh air (when temperatures within the waste rock were lower than the atmospheric temperature) and give off pore gasses when the temperature differences were reversed (a seasonal effect). Warm air rises and colder air sinks. The dump was essentially "breathing." Inhaling during winter and exhaling in the summer. Reactions also created pore gas levels that were in the toxic range. Samples taken in the days following the fatalities from within the monitoring station indicated that the air was essentially depleted of oxygen and contained elevated levels of carbon dioxide. The concentration of oxygen was about 2 percent and carbon dioxide was about 7 percent.

One conduit for gasses expelled from the dump was through a perforated toe drain pipe that exited the dump via a 400-mm- (16-in.) pipe that connected a drain internal to the waste dump to the monitoring station. Geochemical reactions in the waste rock created pore gas levels (and a relatively constant temperature with the waste rock mass) that were at toxic levels.

The video explained how extremely low levels of oxygen can cause unconsciousness within only a few breaths with death coming quickly. High levels of carbon dioxide can have the same effects. The combined effect of these two led to very quick fatalities to the Sullivan Mine victims.

There were numerous conclusions made by the study team, all revolving around the fact that a similar tragedy could occur elsewhere. Facilities or areas on a waste rock or ore pile that are prone to geochemical reactions that could produce pore gasses at toxic levels may include buildings, tents or monitoring stations, low-lying areas or excavations, areas with thick vegetation or local barometric inversions. The study team concluded that the 400-mm- (16-in.) diameter pipe was not the only exposure point that required resolution.

The video was a sobering reminder that geochemistry is not just about water quality or the fulfillment of a regulatory requirement. The video also sparked a good discussion on the need to do complete risk assessments for a variety of events and occurrences — at mine sites and at home.

Following the safety share, Thom Seal, University of Nevada, Reno, gave a Geochemistry 101 presentation, which was a good primer for the day, and a really good summary of the underlying concepts that would be discussed throughout the day.

Acid rock drainage is acidic water (pH <5.0), laden with iron (and possibly other metals) and sulfate, that forms under natural conditions when materials containing sulfides are exposed to the atmosphere or oxidizing conditions. Alkaline mine drainage is water that has a pH of 6 or above, but may still have dissolved metals. ARD results when sulfide minerals in rocks are exposed to oxidizing conditions. Iron sulfides, predominately pyrite, are the major acid producers, but oxidation of other sulfide minerals may release metals and produce acid. These include:

- Arsenopyrite ($FeAsS$)
- Chalcopyrite ($CuFeS_2$)
- Chalcocite (Cu_2S)

- Coyellite (CuS)
- Galena (PbS)
- Marcasite (FeS_2)
- Millerite (NiS)
- Molybdenite (MoS_2)
- Pyrrhotite (Fe_xS_x)
- Sphalerite (ZnS)

The common chemical equations associated with ARD are shown below:

$$2\,FeS_2 + 7\,O_2 + 2\,H_2O \leftrightarrow 2\,Fe_2{+} + 4\,SO_4^{2-} + 4\,H^+ \quad (1)$$

$$2\,Fe^{2+} + 1/2\,O_2 + 2\,H^+ \leftrightarrow 2\,Fe^{3+} + H_2O \quad (2)$$

$$2\,Fe^{3+} + 6\,H_2O \leftrightarrow 2\,Fe(OH)_3 + 6\,H^+ \quad (3)$$

$$FeS_2 + 14\,Fe^{3+} + 8\,H_2O \leftrightarrow 15\,Fe^{2+} + 2\,SO_4^{2-} + 16\,H^+ \quad (4)$$

There is a similar reaction for carbonate rocks:

$$CaCO_3 + 2\,H^+ + SO_4^{2-} \leftrightarrow CaSO_4 + H_2O + CO_2 \quad (5)$$

In Eq. (1), Fe (sulfide, in the form of pyrite, for example) is oxidized, producing ferrous iron (Fe^{2+}), sulfate (SO_4^{2-}) and acid. Ferrous iron in Eq. (2) can be oxidized to form ferric iron (Fe^{3+}). Ferric iron can then either be hydrolyzed and form ferric hydroxide, $Fe(OH)_3$, and acid (Eq. (3)), or it can react with the pyrite and generate greater amounts of ferrous iron, sulfate and acid (Eq. (4)). Of course, you can get some metals precipitating even if the net chemical reaction does not produce an acidic result.

Sulfide-oxidizing bacteria (principally *Thiobacillus ferrooxidans*), accelerates the reaction shown in Eq. (1). The bacterial activity is needed for generation of most ARD, and is primarily responsible for the Eq. (1) reaction.

If any of the processes shown in equations 1 through (4) were slowed or stopped, the generation of ARD would also slow or cease. Examination of the equations indicates:

- Once a sulfide is oxidized to ferric iron, it may be hydrolyzed to ferric hydroxide without the presence of oxygen (i.e., Eq. (3));
- In the presence of ferric iron, sulfides may be oxidized without the presence of oxygen (i.e., Eq. (4)).

Some practitioners have termed this sequence the ARD "engine," as once the process is initiated it is difficult to halt it, even if oxygen is removed from the mix. It may be noted that Thiobacillus are strictly aerobic bacteria and increase the rate of reaction in the presence of oxygen. If the bacteria cannot perform their function in an oxygen-deprived environment, then the ARD reactions may be stemmed.

Equation (5) is typically used to explain the neutralizing reaction by carbonates in an ARD environment. However, the resulting carbon dioxide was one of the factors that led to the disaster at the Sullivan Mine.

The discussion then turned to the geochemistry and metallurgy of gold heap leaching. Seal explained the chemical reactions in a heap leach facility and the benefits of adding lime for pH control, keeping the heap alkaline, and possibly using enough lime not just for aiding in metals recovery, but also to create a net-neutralizing deposit, which may have long-term advantages. Years ago, it was fairly common practice for operators to rinse their heaps at closure. Now, and as indicated in the Global Acid Rock Drainage Guide (GARD Guide), best practices for closed heap leach facilities in Nevada are based on preserving the alkalinity, by not rinsing the heaps. One attendee indicated that it is economical to re-mine some existing heaps to get good lime mixing and additional gold recovery, an operation that may be beneficial for closure.

Terrence Chatwin from the International Network for Acid Prevention (INAP) gave a presentation on the GARD Guide. Chatwin discussed the GARD guide and INAP. INAP is an industry group created to help meet the challenge of effectively dealing with acid drainage. INAP exists to fill the need for an international body that distributes acid drainage information and experience, transferring information and research to better enable practitioners to remain at the forefront of the state of the practice. The GARD Guide aims to be a worldwide reference for acid prevention and to identify best practice in the field of ARD treatment and prevention.

Speaking of information, the roundtable group discussed how baseline data for geochemical modeling could be more adequately collected by having different sectors of the mining operation contributing to the effort. This discussion included topics such as:

- Putting the exploration team in charge of characterization. They would be the most knowledgeable of the geology of the orebody and surrounding rock.
- Additional samples could also be obtained from geotechnical borings.

Geochemical testing lab.

- The mining (ore reserves) staff should account for geochemical characterization in their block models.
- The mine manager and, ultimately, the general manager should have the overall responsibility for the geochemical characterization program. After all, many of today's legacy issues involve water quality/ARD problems. Strong leadership is, therefore, very beneficial.

It is a bit of a conundrum that the final location of the pit walls at closure is required for geochemical modeling (assuming that the basic geology and mineralogical makeup vary spatially in the model). The economics of the orebody during the design phase is usually dictated by what is seen as a conservative commodities price at that time. The commodities price, then, determines the extent of the orebody, and, thus, the final pit walls. Needless to say, the predicted and actual commodities prices seldom coincide at mine closure, and as is often seen today (especially in the precious metals mines), pit expansions are made at what would have been close to the end of the mine life. Thus, the geochemical predictions require updating. The conundrum lies in the fact that it would be most useful to know the actual commodities price that will be in effect at mine closure.

A few ideas were tossed out that are considered best practices:

- It is important to bond correctly for low grade ore stockpiles. If commodity prices are depressed for any period of time, these stockpiles may become waste piles.
- You can reduce risk and expedite the schedule in the permitting process if you have adequate (or even ample) information on geochemical characterization.
- Ecological risk assessments (assessing the potential adverse effects of exposure to contaminants on plants and animals) are more and more commonly being used in pit lake designs.
- Interpretation of short-term geochemical reactions is needed in order to better understand long-term conditions (i.e., lime added to a sample may ward off ARD in a short term test, but might the lime all be consumed over the long run?).
- Consideration should be given to the mechanical/geotechnical changes in PAG-bearing materials comprising mine waste facilities, and how especially the long-term slope stability may change over time.

The day ended with a brief discussion on the topic of commingling tailings and waste rock. This is a really topical issue, and is being investigated at numerous sites around the world as a way for reducing the overall footprint of waste facilities, but also possibly reducing ARD production rates over the long term.

Knight Piésold briefly discussed these possible advantages with the roundtable attendees, and indicated one of the most-studied types of commingled tailings and waste rock is a blend in which tailings just fill the voids in the waste rock. Such a mixture would have the strength properties of the waste rock and the permeability characteristics of tailings. The concept is if the saturation level of the mixture is approximately 85 percent or greater, then the oxygen diffusion rate is nearly zero, and ARD cannot form. Academicians have been studying this for several years. To date, all of this research has been at a fairly small scale. There is currently not a commercially viable method available to blend tailings and waste rock (up to approximately 0.3 m or 1 ft in diameter) into a relatively homogeneous mixture at the rate materials are produced at large-scale mining operations. However, Knight Piésold has been working on a project in which a proprietarily developed mechanism has been proven to blend such dissimilar materials at a bench scale size. It is hoped that this method will be scaled up for field assessments and improvements of the design concept.

Next year's roundtable discussion will center on topics related to commingled tailings and waste rock facilities.

By all accounts, this year's roundtable was seen as being highly successful. Next year, Knight Piésold plans to once again host a roundtable discussion in Elko. ■