Internet Case Study #15:

Prediction of Minesite-Drainage Chemistry Using the "Wheel" Approach

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1. INTRODUCTION

In this last Internet Case Study of the millennium, we offer an overview on the common approach for predicting minesite-drainage chemistry. It allows us to pull together and integrate most of our previous Case Studies at this website.

The prediction of minesite-drainage chemistry is important to mining companies, regulatory agencies, and the interested public. For proposed minesites, prediction will reveal the watersheds and groundwater flowpaths that will likely require controls upon mining. For operating minesites, prediction will indicate if current chemistry could worsen and thus require additional efforts and costs. For closed minesites, predictions of times until improvement can affect security costs and net-present-value estimates of closure costs. Failure to make such predictions can have legal ramifications (our July 1999 Case Study), result in unexpected control costs (our February 1998 Case Study), and can produce environmental effects lasting for many decades (our September 1998 Case Study).

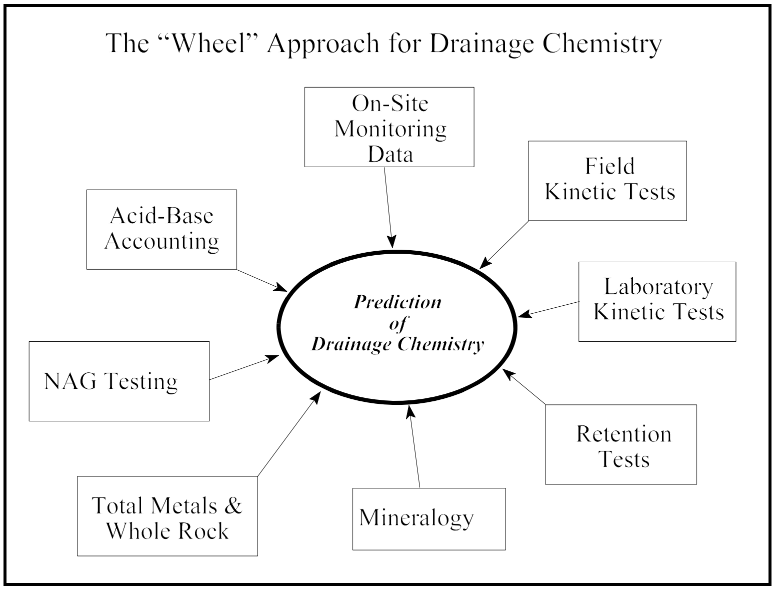

FIGURE 1. The "Wheel" for Drainage-Chemistry Predictions.

It is now widely recognized that no one method or technique is capable of reliably predicting future drainage chemistry. Instead, a combination of tests, sometimes called the "Wheel" approach (Figure 1), is needed. To be clear, the Wheel is not a "toolbox", from which one or two techniques can be drawn, but an integrated approach requiring that most of the techniques be conducted. As someone has pointed out, a bicycle wheel does not work unless most of the spokes are in place, and this holds true of the predictive Wheel.

Due to site-specific limitations and method weaknesses, not all techniques under the Wheel are required or even possible at each minesite. For example, a proposed minesite does not yet have full-scale monitoring data, so this portion of the Wheel would be unavailable. Also, the weaknesses of some methods, like the NAG test, are not yet well understood, so that portion of the Wheel may not be implemented. Nevertheless, as many of the techniques as possible should be conducted and predictions from each compared. If any discrepancies appear, then further work must be done to resolve the discrepancies and to obtain consistent predictions.

Each technique in the Wheel is discussed separately below, beginning with acid-base accounting and going counter-clockwise around the Wheel (Figure 1).

2. ACID-BASE ACCOUNTING

Acid-base accounting (ABA) has been in use for decades to predict whether mined materials will become acidic at some point in time. It can be divided into four basic portions: paste/rinse pH, sulphur species, neutralization potentials, and calculated balances of acid generation and acid neutralization.

To know whether a sample of mined material is currently acidic, near neutral, or alkaline, it is pulverized and mixed with water to obtain “paste pH”. Alternatively, a sample can be taken as-is and rinsed with water to obtain a “rinse pH”.

Implicit in sulphur species is the recognition that not all sulphur generates acidity upon oxidation. For example, sulphate (SO_4^{2-}) is already full oxidized under natural conditions and thus cannot oxidize. On the other hand, sulphide (S^{2-} and S_2^{2-}) will generate acidity upon oxidation, as do intermediate sulphur species like thiosulphate (e.g., S_2O_4). Therefore, it is important to identify all significant sulphur species in a sample and only use the acid-generating species to calculate an Acid Potential (AP).

In opposition to acid-generating sulphur and AP, neutralization potentials (NP) reflect the presence of one or more acid-neutralizing minerals. There are several methods for measuring NP (our November 1997 Case Study), but none provide the “effective” NP that would be applicable under field conditions. This is derived by adjusting measured NPs based on information from other techniques in the Wheel.

The two calculated balances are known as “Net Neutralization Potential” (NNP = NP - AP) and “Net Potential Ratio” (NPR = NP/AP). In places like Australasia, the NNP equation is often reversed to obtain “Net Acid Producing Potential” (NAPP = AP - NP). In all cases, the point is to predict if a sample will generate net acidity at some point, even if there is a lag time due to NP (our March 1999 Case Study). To prevent the onset of net acidity, there has to be a significant excess of NP over AP, but this is too detailed to discuss here.

ABA has its strengths and weaknesses, like all techniques in the Wheel, and many are well understood. Nevertheless, discrepancies can still arise between ABA and the other techniques, indicating additional work must be done to understand and resolve any discrepancies.

3. NAG TEST

The NAG Test involves the addition of hydrogen peroxide to a sample, which causes any sulphide to oxidize quickly and generate acidity. Based on the measured pH (“NAG pH”) and the amount of acid generated (“NAG Value”), the sample is declared to be net-acid-generating or non-net-acid-generating.

If net acid generating, the NAG value provides an estimate of the net capacity, similar in concept to NNP in ABA above. Unlike ABA, the NAG Test does not give an estimate of NP.

There have been major discrepancies between predictions based on ABA and those based on NAG for the same samples (our January 1999 Case Study). Although the discrepancies can be biased in either direction, the NAG Test more often underestimates the net-acid-generating capacity compared to ABA. However, there is not enough information from most minesites to determine which technique, if either, is correct, because rarely has the Wheel approach been used at sites performing NAG Tests. Nevertheless, it is clear that the NAG Test has strengths and weaknesses, although these are not as well defined as for other Wheel techniques.

Detailed studies are reportedly underway, such as in Australia with AMIRA, to resolve and explain the discrepancies between NAG and ABA, presumably involving the full Wheel approach. This will hopefully allow the NAG Test to be fully integrated into the Wheel by illustrating its strengths and weaknesses and by explaining its contribution in interpreting the other techniques.

4. TOTAL METALS AND WHOLE ROCK

These techniques delineate the elemental composition of a sample. When combined with ABA (above), mineralogy (below), and kinetic tests (below), this information assists in defining a sample’s capacities for acid generation, acid neutralization, and metal leaching and in calculating depletion times of various minerals and metals under the measured kinetic reaction rates.

5. MINERALOGY

Interestingly, a sample’s mineralogy is a critical aspect in the prediction of its acid generation, acid neutralization, and metal leaching (our November 1997 Case Study), but mineralogy cannot often be closely compared to the other techniques in the Wheel. This is because (1) mineralogy often is based on visual examinations and is thus not as accurate as other Wheel techniques and (2) the reactivity of a mineral can vary with small changes in elemental composition and other crystallographic features and thus can vary significantly from minesite to minesite. Nevertheless, even a general understanding of a minesite’s mineralogy can be critical in obtaining reasonable predictions from the Wheel.

6. RETENTION TESTS

For mined materials that are already weathered, the weathering reaction products are not always entirely removed by precipitation and infiltration. In fact, typically only a small percentage of reaction products generated each year are removed. Thus, they are “stored” on the surfaces of the mined materials, often as secondary minerals, and can be removed at a later time. These slowly dissolving retained reaction products can affect drainage chemistry long after the reactive primary minerals are exhausted. Alternatively, if weathered mined materials are submerged underwater or below a water table, fast-dissolving reaction products can quickly release a massive loading into this water.

To determine the amount of retained reaction products and their rate of dissolution, retention tests are conducted, ranging from simple washing with water to sequential-extraction tests. In the case of fresh unweathered materials, these retention tests would only reflect the short-term dissolution of the fresh, primary minerals rather than the accumulated secondary minerals. The reaction rates of primary minerals are more reliably obtained from laboratory kinetic tests (below).

7. LABORATORY KINETIC TESTS

These tests basically fall under two categories: Sobek humidity cells and columns (results from hundreds of kinetic tests at many dozens of minesites are compiled in the International Kinetic Database). Sobek humidity cells are designed to remove as much of the weekly reaction products as possible and thus provide bulk reaction rates of the primary minerals (“Rate1”). On the other hand, columns are often designed to allow reaction products to accumulate. As a result, columns may provide an estimate of on-site concentrations (“Rate2”), rather than primary reaction rates which are typically higher, with the difference represented by retained reaction products (see Retention Tests above).

Unfortunately, some cells are operated like columns, and some columns are operated like Sobek cells, resulting in confusion and the inability to properly interpret the results. This can, in turn, lead to significant errors in predictions (see our 1998 paper available under Downloads).

There have been some criticisms of laboratory kinetic tests because of their lack of consideration for bacterial activity. However, this is not correct and does not affect results significantly (our November 1998 Case Study).

8. FIELD KINETIC TESTS

Field kinetic tests are often larger versions of laboratory columns (above) and often involve over one tonne of material placed in a large canister or laid on a low-permeability base. Because they are often operated like columns, they provide estimates of on-site concentrations, rather than primary-mineral reaction rates, and they often retain reaction products. Wheel studies have shown, for example, that aqueous concentrations (as mg/L) from two tonnes of waste rock are similar to those from 50,000 tonnes, which is expected when the same secondary minerals form to retain the reaction products.

Field kinetic tests can be valuable substitutes when full-scale minesite components (our March 1998 Case Study) do not yet exist at a site and thus full-scale monitoring data (see below) are not available.

9. ON-SITE MONITORING DATA

If a minesite already exists, the actual monitoring of its drainage is a critical technique under the Wheel. The monitoring data can be useful for (1) developing a statistical summary of present drainage chemistry and future drainage chemistry if pH is expected to change (our January 1998 and March 1999 Case Studies), (2) determining the appropriate drainage-chemistry controls (our December 1997 and September 1999 Case Studies) and the costs of those controls (our February 1998 Case Study), (3) deciding whether attempts should be made to reduce concentrations leaving a minesite component (our July 1998 Case Study), and (4) ensuring the physical and chemical processes are understood so that drainage-chemistry controls will be successful (our May 1998 and May 1999 Case Studies).

10. CONCLUSION

The Wheel provides an integrated and partially redundant approach for predicting drainage chemistry. Because it involves several techniques, it draws on the combined strengths to develop reasonable predictions. However, because of the weaknesses, there will sometimes be discrepancies between techniques. Any discrepancies should be resolved with further work to demonstrate they are from the weaknesses or that they revealed real unforeseen factors. More details can be found in Environmental Geochemistry of Minesite Drainage: Practical Theory and Case Studies.