ACID MINE DRAINAGE REMEDIATION WORKSHOP
NTC-TV Broadcast
January 24, 2002

REGIONAL SITE CHARACTERIZATION

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Objective: to show how geology and physical and climatic conditions affect the formation and migration of acid drainage.

GEOLOGY AND THE NATURAL ENVIROMENT

Complete characterization of the geology and natural environment, also known as regional or site characterization, is essential in order to understand the entire ecosystem being remediated. Remediation of an entire watershed is typically unrealistic. The extent, sources, and effects of potential contamination are characterized and prioritized. Pre-mining conditions are estimated in order to establish realistic and affordable remediation goals. A conceptual model of the geologic, geochemical, and hydrologic processes is developed and tested during the regional site characterization. Obvious point sources may not always be responsible for decrease in the drainage quality; regional site assessments should determine all point and non-point sources of potential contamination. Regional site characterization must be responsive to both regulatory and scientific objectives. One of the major objectives is typically successful remediation of a particular site. Unsuccessful remediation may have substantial impacts on the entire watershed, including acid mine drainage, erosion, sedimentation, subsidence, differential settling of fills and regraded mine areas, exposure and possible release of toxins, loss of recreational opportunities, and destruction of geomorphic features. An understanding of the subsurface geology and ground water flow is critical.

Components of regional site characterization

- Regional geology (geologic map)
- Establish background/existing conditions/characterizing reference/ baseline (Alpers and Nordstrom, 2000; Matschullat et al., 2000)
- Define baseline (current) conditions
- Identify and quantify existing and potential sources (geological), transport or migration (hydrologic and geologic), and effects of potential contamination (biological key issues)
- Characterize target sites and processes affecting contaminant dispersal
- Characterize the health of the ecosystem

_ Develop remediation goals and monitoring studies
_ Provide and utilize data
_ Document lessons learned for future applications

Questions to ask during the site characterization, include:
_ What is the purpose or objective of your project?
_ What to look for on a site in order to develop successful remediation plans?
_ What site-specific information is available from state and federal records?
_ How to develop a site characterization plan?
_ Identify impacted (mine, human, loggings, agriculture, other) areas vs. pristine areas.
_ How to interpret subsurface data, geologic, and hydrologic?
_ What types of monitoring may be required?

TYPES OF GEOLOGIC DATA REQUIRED

To answer these questions a variety of data for characterizing the geology and natural environment must be collected and includes the following:

Knowledge of the climatic conditions at the mine site is critical in understanding the formation, migration, and control of acid drainage. One of the very first things a company should do is to establish a weather station at the mine site. The earliest weather data can be collected, the better. Precipitation history at the specific site, which is critical in ground-water models and modeling of acid drainage, is needed. Too many times, precipitation and flood potential data from tens or even hundreds of miles away are used and can result in erroneous predictions and modeling of acid drainage. The type of climate (arid, humid, mountainous, ect.) controls the amount of water available to generate acid drainage. It also is important to understand that microclimates are common at some mine sites. Environmental impacts may be delayed in semi-arid and arid environments (Kempton and Atkins, 2000). Are climatic conditions appropriate to form natural or constructed wetlands that may remediate AMD (Walton-Day, 1999)?

Specific climatic data

Temperature
Evapotranspiration
Rainfall (precipitation history)
Snowfall
River flow/floods (10 yr, 100 yr, ect.)
Freeze-thaw
Growing season
Days of sunlight

Physical data/characteristics

Topography (topographic maps)
Altitude
Natural drainage vs. man-made drainage
Wind direction and speed
Storm events and types

Slope aspects
Stream flow data

Geology (Environmental characteristics of mineral deposits)
Lithology/host rocks/ stratigraphy
Structure/faults/joints/fractures/extent of deposit
Type of mineral deposit
Mineralogy
Alteration
Zoning
Chemistry (what elements are in the deposit and adjacent to the deposit that could cause problems)
Ore body properties
Subsurface geology
Hydrogeology and surface water
Surface-ground water interaction
Use of water as an exploration tool can also be used for environmental purposes
Particle size analysis
Geomorphology
Seismic data/earthquake prediction

Mining history and impacts of mine workings (pumping, dewatering, pit lakes)
Mining methods
Processing techniques
Location (disposal) of operational units

Biology (plants, animals, microorganisms, humans, habitats; tests are not adequate to measure bioavailabilty, if concerned about a plant or animal, ect having a problem- then measure that media)

Types of metal deposits

The type of mineral deposit dramatically affects the potential impact on drainage quality. Different deposit types contain different suites of mineralogy and characteristic geochemical signatures that may impact soils, sediments, and drainage quality. In coal deposits, pyrite is the controlling factor that may produce AMD. Although, pyrite is also a major factor in producing AMD in metal mines, other sulfide minerals as well as other minerals play important roles in affecting drainage quality in and near mine sites. The mineralogy is a direct consequence of the type of mineral deposit.

Numerous classifications have been applied to mineral deposits to aid in exploration and evaluation of metallic resources (Lindgren et al., 1910; Lindgren, 1933; Eckstrand, 1984; Guilbert and Park, 1986; Cox and Singer, 1986; Roberts and Sheahan, 1988; Sheahan and Cherry, 1993). Early classifications were based on the form of the deposit or a combination of form and perceived chemical conditions of formation, such as Lindgren's (1933) classification of mineral deposits associated with igneous rocks into epithermal, mesothermal, and hydrothermal. In the 1960s and 1970s, wide acceptance of plate tectonic theories led to the recognition that similar mineral deposits occur in areas of similar tectonic settings and resulted in classifications of mineral deposits according to tectonic settings (Sillitoe, 1972, 1981; Guilbert and Park, 1986). In the 1980s, mineral deposit models became popular which incorporated tectonic setting and physical and chemical characteristics of the deposits (Cox and Singer, 1986; Roberts and Sheahan, 1988; Sheahan and Cherry, 1993). These classifications aided in the exploration of many mineral deposits.

In the 1990s, the USGS redefined their classification of mineral deposits in terms of an environmental geochemical classification (du Bray, 1995; Plumlee, 1999). Conceptual models have been developed to predict the chemical and physical response to weathering and environmental processes. Some of the geologic factors that affect drainage quality are summarized in Table 1.

TABLE 1—Geologic characteristics of mineral deposits that affect soil, water and drainage quality (modified from Plumlee, 1999).

Characteristic	Controls	Remarks
Iron sulfide content	Chemical	Oxidation produces acidic waters and also supplies ferric iron which is an aggressive oxidant.
Concentration of other sulfides	Chemical	Some generate acid during oxidation, release of metals during oxidation causes degradation of drainage quality
Concentration of carbonate, alluminosilicate, and other nonsulfide minerals	Chemical	Many of these minerals can consume acid, iron and manganese carbonates can produce acidic waters under certain conditions
Minerals resistant to weathering	Physical, chemical	Controls release of metals and drainage quality.
Secondary minerals	Chemical, physical	Soluble secondary minerals can store acid and metals that can be release when the minerals are dissolved.
Pre-mining and pre-erosion weathering and oxidation	Chemical	Reduces the potential for sulfide deposits to generate acid.
Host rock lithology	Chemical, physical	May consume or generate acid. May increase or decrease resistance to erosion.
Wallrock alteration	Chemical, physical	May consume or generate acid. May increase or decrease the ability of the rock to transmit ground water. May increase or decrease resistance to erosion.
Major and trace elements	Chemical	Can affect metal mobility and drainage quality.
Form of the ore body (vein, disseminated, massive, placer)	Physical	Controls weathering.
Porosity, hydraulic conductivity of host rocks	Physical	Controls weathering.
Nature and extent of faults, fractures and joints	Physical	Controls weathering.
Deposit grade and size	Physical, chemical	Controls magnitude of adverse drainage quality.
Mineral and alteration zoning	Physical, chemical	May cause variations in environmental signatures, which may affect drainage quality.

Country rocks surrounding most metal and some industrial minerals deposits exhibit reaction effects from circulating waters that can change the mineralogical composition by physical and/or chemical means. During formation of mineral deposits, some elements may move from the host rock into the fluid, while other elements move from the fluid into the host rock, as previously explained in the section on solutions and mineral chemistry (Susak, 1994)). These effects are collectively known as alteration. The altered country rocks vary in extent, from a few millimeters to many kilometers from the vein or mineral deposit and form alteration zones, halos, envelopes, or selvages (Guilbert and Park, 1986). The alteration zones or halos are typically more widespread than the actual mineral deposit and can aid exploration geologists in locating the mineral deposits. Pyrite is a common alteration mineral and may be responsible for natural acidic water in some mining areas (Plumlee, 1999; Plumlee et al, 1999). Clay alteration is also common in many mineralized areas and may actually neutralize acidic drainage. Alteration zoning further complicates drainage quality in many mineralized areas.

LITHOLOGIC AND STRATIGRAPHIC FACTORS AFFECTING MINE DRAINAGE QUALITY

- Presence of limestone, other carbonate rocks, andesite, or other rocks that could neutralize AMD
- Presence of alteration halos or other pyrite-bearing rocks that could produce natural AMD
- Presence of permeable rocks that would allow ground water flow
- Presence of impermeable rocks that would restrict ground water flow

SURFACE AND GROUND WATER FACTORS AFFECTING MINE DRAINAGE QUALITY

- Surface water typically originates from meteoric water (precipitation).
- The chemistry (dissolved and particulate) of the water is dependent upon the chemistry of the air, geology, and biology through or over which it flows.
- Surface waters are not infinite and are not distributed equally geographically or demographically.
- The ultimate end of surface and some ground water flow is the ocean, which is a major repository of contaminants (unless the contaminants are removed before reaching the ocean).
- Porosity, permeability, and grain size of the host rocks control ground water flow.
- Saturated verses unsaturated.
- Stormwater diversion and control facilities.
- pH and heavy metal concentrations.
- Concentration of other elements (aluminum, iron, sulfate, ect.)
- Total suspended mater and resultant turbidity.

Ficklin plot (Ficklin et al., 1992)

The Ficklin plot is a plot of pH verses total metal content (the sum of Zn, Cu, Cd, Cu, Co, Ni, Pb concentrations) of mine waters draining from diverse mineral deposits (Ficklin et al., 1992). The purpose of the plot is to help predict the metal content of waters derived from specific types of mineral deposits. For example, if the mineral deposit is a pyrite-rich massive sulfide ore (field A), then the waters derived from that deposit are likely to have low pH with a high total metal content. If the mineral deposit is pyrite-poor, Au-Te vein and breccia deposit with carbonate ganguage (field K), then the waters derived from the deposit are likely to be high pH with a low metal content. Also, if you know the water chemistry, you can use this plot to predict the mineral deposit type. It must be emphasized that this should be used as a predicative tool and not absolute. Some waters from specific mineral deposit types may plot outside of the indicated fields.

Mining methods and their effects on mine drainage quality

There are basically four types of mining; surface, underground, placer, and solution mining. Summaries of the types of mining are by Stout (1967, 1980), Thomas (1973), Hartman (1992), U.S. Environmental Protection Agency (1997), Gertsch and Bullock (1998), and Whyte and Danielson (1998).

Surface mining involves the extraction of minerals or other commodities that are located close to the surface by removing soil and rock overlying the deposit. Surface mining typically requires five steps: overburden removal, blasting, muking, primary crushing, hauling, and backfilling. There are three types of surface mining: strip, open pit, and quarry.

Underground mining involves the extraction of minerals or other commodities that are too deep in the subsurface to be mined by surface mining techniques. There are numerous underground mining techniques; room and pillar and shrinkage stopes are two of the more popular. Underground mining typically requires six steps: loading and blasting, stoping, mucking, ore haulage, skipping ore to the surface, and backfilling. Although underground mining does not generally require as much surface disturbance as surface mining, some waste material is brought to the surface and surface facilities can be extensive.

Placer mining is a variation of surface mining where natural concentrations of heavy minerals, such as gold, tungsten, tin, apatite, ect. are found. Placers are generally found in alluvial fan deposits, bench or terrace gravel deposits, river-bars, and stream deposits or as residual placers formed directly on top of lode deposits. During fluvial events, large volumes of sediment containing heavy metals are transported and deposited in relatively poorly-sorted alluvial and stream deposits. The mineral concentrates by gravity in incised stream valleys and alluvial fans in deeply weathered highlands. Traditional methods of placer mining were by panning, sluicing, and the use of a rocker. Miners would divert streams, sending smaller streams off to each side, leaving streambeds exposed. The dry conditions of summer and early fall were ideal as low water levels exposed areas where gold was hiding. Later hydraulic mining was the preferred method of mining in placer deposits. Water would be transported to the placer by canals or ditches, and forced into a hose. The beginning of the hose was larger and higher than the opposite end, which would have a pipe attached to it, so the weight of the water going into the hose would force it out the other end at great pressure. A jet of water would cut into the hillside, washing the dirt and gravel down into a sluice box. This method of mining, due to the scale of production and speed of extraction, had vast environmental impacts, including sedimentation and erosion. In Alaska and other cold areas, locally steam or wood burning thawed the gravels.

Solution mining is a specialized mining technique that involves certain commodities that are easily dissolved or melted or are in a liquid state. Solution mining requires wells similar to oil and gas production. A leaching solution, typically acidic, is injected into the ore body, dissolves the ore, and is extracted by extraction wells. The host rock must be permeable and allow fluids to be extracted by pumping. Currently five commodities, uranium, copper, salt, potash, and sulfur, can be economically recovered by solution mining techniques.

Extractive metallurgy and their effects on drainage quality

Extractive metallurgy involves the extraction of metals from the ore. Typically, the ore is mined and sent to a facility for crushing, grinding, screening, and sizing (i.e. liberation). Then the material is sent to a mill for either chemical separation (i.e. leaching, common to some gold and uranium deposits) or physical separation (gravity, flotation, magnetic, or electrostatic). A concentrate is produced, which is sent either for leaching (some zinc deposits) or smelting. The smelted material may then go to a refinery for final processing. Coal is typically crushed, ground, screened, and sized and then physically separated by gravity or flotation methods, resulting in a clean coal product that is ready for market. At each step, waste material is produced that must be disposed of. These waste piles and processing fluids can be source of acid mine drainage or other effects to drainage quality. Summaries of extractive metallurgy techniques are by Biswas and Davenport (1980), Gilchrist (1980), Mackey and Prengaman (1990), Gill (1991), Leonard and Hardinge (1991), and Wills (1992).

TABLE 2: Field checklist for site assessment (modified from Kwon, 1993).

MATERIAL	MEASUREMENTS AND OBSERVATIONS
Geologic map	Scale of map (Is it detailed enough?) Completeness (Does it show mine workings, lithology, ect.?)
Rocks (ore, host rock, altered rock, barren country rock)	Lithology Mineralogy and texture Nature and extent of weathering Fractures, joint density, water flows along fractures Efflorescent salts
Natural weathering products (gossan, soil, sediment) Mine waste Tailings	Mineralogy and texture Color Moisture content Profile development Paste pH Presence and condition of vegetation Erosion Efflorescent salts Presence and distribution of hardpans Presence and distribution of seeps
Water bodies	pH, conductivity, alkalinity, dissolve oxygen Presence of secondary minerals Evidence of microbes (biofilms)
Other considerations	Weather (precipitation, temperature, humidity) Climate zone (weathering rate, metal transport) Proximity of waste to an area of risk (stream, wetland) Site accessibility Topography Vegetation (natural wetlands, barren areas)

EFFECTS OF WEATHERING ON MINE DRAINAGE QUALITY

_ Oxidation of pyrite and other sulfide minerals may produce AMD
_ Dissolution of soluble sulfate, hydroxide, and other secondary minerals containing heavy metals may produce AMD
_ Erosion and sedimentation may affect drainage quality
_ Mine stability (subsidence) may affect drainage quality

SOURCES OF GEOLOGIC, GEOCHEMICAL, AND HYDROLOGIC DATA

_ State geological surveys
_ U.S. Geological Survey
_ Universities (theses, dissertations, other research)
_ Other state and federal agencies (U.S. Bureau of Land Management, U.S. Forest Service, U.S. Park Service, U.S. Environmental Protection Agency, U.S. Bureau of Reclamation, Office of Surface Mining, ect.)
_ Scientific journals (GeoRef and other search mechanisms)
_ Environmental impact studies
_ Company reports (many states have archives of such data for historic mines)

_ Anaconda Geological Document Collection, American Heritage Center, University of Wyoming
_ Databases (NURE, STORAT, ect.)
_ smelter reports
_ assays
_ metallurgical reports

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