What are Metal Leaching and Acid Rock Drainage and Why are They Important to Mining?

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What are Metal Leaching and Acid Rock Drainage?
Metal leaching and acid rock drainage are terms used to describe drainage from sulphidic geological materials exposed to the weathering agents oxygen and water.
Sulphidic geologic materials are geologic materials containing sulphide minerals and/or the products of sulphide weathering, processing or hydrothermal alteration.

### Some Common Sulphide Minerals

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
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</thead>
<tbody>
<tr>
<td>Pyrite</td>
<td>FeS(_2)</td>
<td>Arsenopyrite</td>
<td>FeAsS</td>
</tr>
<tr>
<td>Pyrrhotite</td>
<td>Fe(_{(0.83-1)})S</td>
<td>Chalcocite</td>
<td>Cu(_2)S</td>
</tr>
<tr>
<td>Marcasite</td>
<td>FeS(_2)</td>
<td>Bornite</td>
<td>Cu(_5)FeS(_4)</td>
</tr>
<tr>
<td>Galena</td>
<td>PbS</td>
<td>Chalcopyrite</td>
<td>CuFeS(_2)</td>
</tr>
<tr>
<td>Sphalerite</td>
<td>(Zn,Fe)S</td>
<td>Tetrahedrite</td>
<td>(Cu,Fe,Ag,Zn)(_{12})Sb(<em>4)S(</em>{13})</td>
</tr>
<tr>
<td>Cinnabar</td>
<td>HgS</td>
<td>Pentlandite</td>
<td>(Ni,Fe)(_9)S(_8)</td>
</tr>
<tr>
<td>Stibnite</td>
<td>Sb(_2)S(_3)</td>
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</tr>
<tr>
<td>Molybdenite</td>
<td>MoS(_2)</td>
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Weathering is the processes by which particles and rocks are altered on exposure to surface temperature and pressure, and atmospheric agents such as air, water and biological activity.

In a process analogous to the decomposition of a leaf when it falls from a tree, rock physically and chemically degrades when exposed to air and water.
Many weathering reactions are very slow, taking millions of years and are environmentally insignificant.

Sulphide oxidation and the dissolution of sulphide oxidation products are relatively fast and may be environmentally significant.

**Pyrite**

\[
\text{FeS}_2 + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + 2\text{SO}_4^{2-} + 4\text{H}^+
\]
Sulphide oxidation and the dissolution of its products is important because:

– these minerals contain potentially toxic elements
– oxidation transforms relatively insoluble sulphide minerals into far more soluble chemical compounds.

**Sphalerite:**

$$\text{ZnS} + \text{O}_2 \rightarrow \text{Zn}^{2+} + \text{SO}_4^{2-}$$

**Chalcopryrite:**

$$\text{CuFeS}_2 + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + \text{Cu}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+$$
Dissolution is important because dissolved elements can be transported by surface and ground water, and are far more readily absorbed by sensitive receptors.
The term ‘metal leaching (ML)’ is used because major metals such as Fe and Al and trace metals such as Cu, Ni, Pb and Zn are the most common environmental problems associated with sulphidic mine drainage.

(from Gammons, 2009)
The other mechanism by which the oxidation of sulphide minerals can have an adverse impact on drainage chemistry is through the production of acid, which if not neutralized, will lower the pH.

**Acid generation by pyrite oxidation**
\[
\text{FeS}_2 + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + 2\text{SO}_4^{2-} + 4\text{H}^+
\]

**Acid neutralization by calcite**
\[
\text{CaCO}_3 + \text{H}^+ \rightarrow \text{Ca}^{2+} + \text{HCO}_3^- \quad (\text{pH} > 6.3)
\]
Acid may also be produced by the dissolution of acidic sulphate minerals.

Melanterite:

\[
\text{FeSO}_4\cdot7\text{H}_2\text{O} + \text{O}_2 \rightarrow \text{Fe(OH)}_3 + \text{SO}_4^{2-} + \text{H}_2\text{O} + 2\text{H}^+
\]

Acid producing sulphate minerals (e.g., iron and aluminium sulphate) primarily occurs in rock that is already acidic.
A decrease in pH adversely impacts drainage chemistry by increasing both:

- the solubility of many elements; and
- the rates of sulphide oxidation and other weathering reactions, releasing even more potential solutes.
Metal solubility vs. pH (from Gammons, 2009)
The rate of sulphide oxidation increases exponentially with a decrease in pH below 3.5.

From Williamson et al., 2006
The term ‘acid rock drainage (ARD)’ is used for drainage from sulphidic geological materials because impacts are more common and most of the worst impacts have occurred where drainage is acidic.
It is important to note that even though concentrations are lower than at acidic pH many elements (e.g., arsenic, nickel and zinc) may still be above environmental guidelines in near-neutral and alkaline drainage.

The solubility of molybdenum, arsenic and selenium may be higher in near-neutral and alkaline than acidic drainage.

Two of the most costly mitigation programs at BC mines are due to elevated molybdenum and arsenic in near-neutral drainage.
It is also important to note that the elements and processes associated with sulphidic geological materials at mine sites all occur to a limited degree in healthy ecosystems.

The question is not whether the chemical species will be present, but whether their release will be large enough to cause significant environmental impacts.
Why are Metal Leaching and Acid Rock Drainage from Mines Important?
Many Non-Mining Examples of ARD

Marine Soils drained for farming (Boundary Bay)
Highways (Okanagan Connector and Island Highway)
Forestry roads on Northern Vancouver Island and Queen Charlotte Island
Halifax Airport
ML/ARD is a concern for mines because:

- Most base and precious metal, and many coal, uranium and diamond mines excavate sulphidic rock.
ML/ARD is a concern for mines because:

– mines can expose large amounts of sulphidic rock to oxygen and water;

– the products - waste rock, tailings and mine workings - remain after mining.
Historically, drainage chemistry from mining has resulted in extensive impacts to aquatic resources and huge clean-up costs.

A failure to adequately assess and deal with ML/ARD has resulted the public paying many $100s of millions to clean-up and prevent additional impacts.

Due to ARD, mining is widely perceived as environmental “spoiler”.
Over the last 15 years, recognition of the large costs and technical challenges has resulted in mines being planned and operated in a manner that better protects the environment.
The environmental objectives for mines with sulphidic geological materials include:

- preventing exceedance of drainage and atmospheric discharge limits;
- minimizing on-site human/ecological/safety risks;
- restoration of land use;
- sustaining use of national and corporate mineral resources; and
- maintaining good regulatory and corporate images.