
# The Often-Overlooked Environmental Impacts of Sulphide Oxidation: Neutral and Saline Rock Drainage

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# Introduction

- Geochemistry is often the primary driver of environmental compliance challenges of mines
- Geochemistry characterization tends to be focused on acid rock drainage (ARD) / sulphide oxidation
- Metal loading from neutral rock drainage and saline drainage (NRD/SD) can be comparable to those released with ARD

# Environmental Impacts of Mine Drainage

- Reduced quality of surrounding water
- Pollution of drinking water sources
- Decreased aquatic animal populations
- Injury and/or death to terrestrial animals
- Injury and/or death to plant species

# Why does it matter?

- Mine water impacts represent single largest waste stream in the world
- In North America, there is ten times more solid mine waste produced than household garbage
- Waste blending is a commonly applied waste management technique

# What is NRD/SD?

- pH of drainage above 6.0
- NRD less than 1,000 mg/L sulphate
- SD greater than 1,000 mg/L sulphate

# Minerals Related to Ore Deposits

| Mineral | Composition |
|---|---|
| Pyrite | $FeS_2$ |
| Marcasite | $FeS_2$ |
| Chalcopyrite | $CuFeS_2$ |
| Chalcocite | $Cu_2S$ |
| Sphalerite | ZnS |
| Galena | PbS |
| Millerite | NiS |
| Pyrrhotite | $Fe(1-x)S$ (where $0<x<0.2$) |
| Arsenopyrite | FeAsS |
| Cinnabar | HgS |

(Source: Ferguson and Erickson 1988)

# Oxidation of Sulphides

Overall Oxygen Controlled Reaction:

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 14Fe(OH)_3 + 8H_2SO_4$$

Step 1: $FeS_2 + {}^{7}/_{2}O_2 + H_2O \rightarrow 2SO_4^{2-} + 2H^+ + Fe^{2+}$

Step 2: $Fe^{2+} + {}^{1}/_{4}O_2 + H^+ \rightarrow Fe3+ + {}^{1}/_{2}H_2O$

Step 3: $Fe^{2+} + {}^{1}/_{4}O_2 + {}^{5}/_{2}H_2O \rightarrow Fe(OH)_3 + 2H^+$

Overall Iron Controlled Reaction:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

(at pH less than 3.0)

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# Dissolution of Carbonates

$$MCO_3 + 2H^+ \leftrightarrow M^{2+} + CO_2 + H_2O \text{ (below a pH of 6)}$$

$$MCO_3 + H^+ \leftrightarrow M^{2+} + HCO_3^- \text{ (above a pH of 6 )}$$

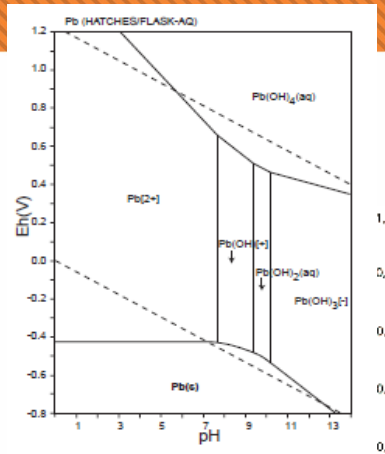
$$MAl_2Si_2O_8 + 2H^+ + H2O \leftrightarrow M^{2+} + Al_2Si_2O_5(OH)_4$$

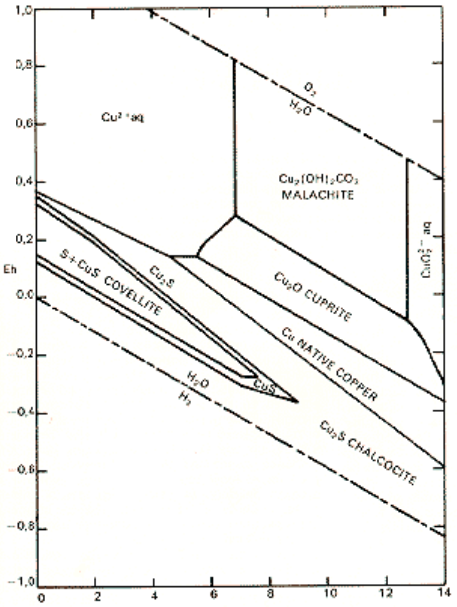
- For most divalent metals the $CO_3^{2-}$ is more basic than $M^{2+}$ is acidic
- The acidity of $M^{2+}$ is controlled by ability to release $H^+$ when forming metal-hydroxo complexes and ability to bind free $OH^-$

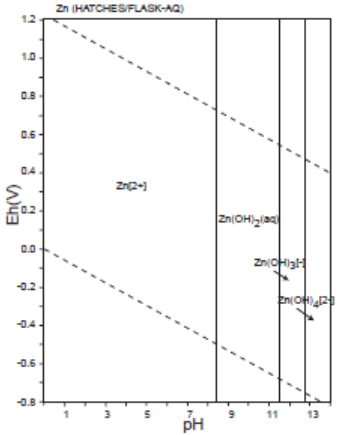
# Metals of Concern in NRD/SD

- Zinc
- Molybdenum
- Arsenic
- Antimony
- Chromium
- Copper
- Lead
- Nickel
- Selenium
- Sulphate

- Copper, zinc, cadmium, and lead readily form complexes with sulphides and carbonates
- Mobility strongly influenced by presence of iron oxyhydroxides
- Under reducing conditions more likely to be mobilized in solution

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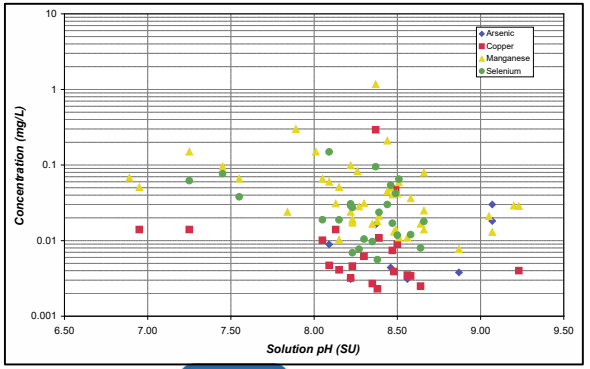
- Mobility in solution depends on pH and redox
- Under oxidizing conditions:
  - Arsenic will be arsenate (analogous to phosphate)
  - Selenium will be selenate (analogous to sulphate)
- Under reducing conditions:
  - Arsenic will be arsenite
  - Selenium will be selenide
- Under intermediate redox conditions:
  - Selenium will be selenite
- Iron oxyhydroxides can adsorb arsenate and selenite

# Examples of NRD/SD Impacted Waters

- Mine site in Finland with a high sulphide and low sulphide discharge (Heikken et al., 2009)
  - High sulphide discharge typical of ARD, except pH
    - Neutral pH; elevated metals - Ni, Mn, Cu, Zn, Co
    - Elevated manganese due to carbonate dissolution
  - Low sulphide discharge (neutral pH; only elevated Ni)
  - Water quality heavily influenced by presence or absence of oxyhydroxides

# Examples of NRD/SD Impacted Waters (cont.)

- Greenfield copper mine (southern Arizona)
  - Baseline characterization identified Cu, Zn, Fe, Al, Mg, K, Mn, and Na as the most abundant trace elements
  - Kinetic testing showed neutral pH conditions
    - Laboratory testing mostly non-detect for metals
    - Field testing resulted in higher concentrations
      - Measurable Cu, Mn, As, Se, and Zn in leachate
      - Due to water rock ratio and particle size

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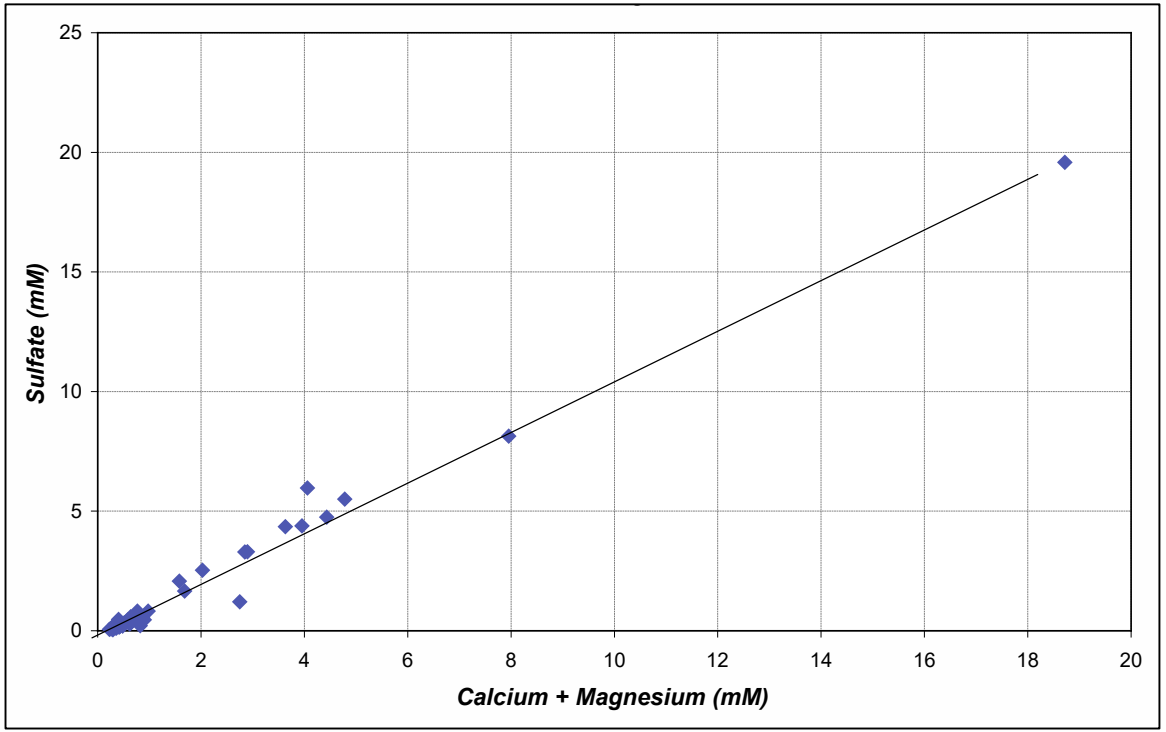
- When sulphate produced due to sulphide oxidation is neutralized by carbonate dissolution ratio of carbonate to sulphate is 2:1
- When sulphide oxidation reactions are not being neutralized, sulphate concentrations remain steady over time

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# Conclusions

- Both ARD and NRD/SD have the potential to result in poor water quality
  - Significant metal or dissolved solids loading
- Waste blending can still lead to adverse discharge conditions
- Baseline characterization studies should consider the potential of NRD/SD

**Thank You!**

**Questions?**

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