Overview of Mine Water Classification & its Genesis

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Outbursts of Water from the Slovenian Abandoned Mines
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Six major schemes for classifying mine water exist:

- Facies diagrams (Piper 1944 & Durov 1948)
- Glover’s scheme (1975)
- Ficklin et al. (1992)
- Younger’s scheme (1995)
- Azzie’s scheme (2000)
Piper Diagram

CATIONS

ANIONS

Mg

Na + K

HCO₃ + CO₃

SO₄

Ca

Cl

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Glover’s Scheme

1. Acidic with low $\text{Fe}_{\text{TOTAL}}$ conc.

2. Acidic with high $\text{Fe}^{3+}$ conc.

3. Acidic with high $\text{Fe}^{2+}$ conc.

4. Neutral with high $\text{Fe}^{2+}$ conc.

5. Suspended ferric hydroxide (combined with dissolved $\text{Fe}^{2+}$ or $\text{Fe}^{3+}$)
High acid, Extreme metal
High acid, High metal
Acid, High metal
Near-neutral, High metal
Acid, Low metal
Near-neutral, Low metal
Near-neutral, Ultra low metal

Zn + Cu + Cd + Ni + Co + Pb (mg/L) vs pH
GROUP 1:
   Net alkaline minewaters
   i.e. alkalinity > acidity

GROUP 2:
   Net acidic mine waters
   i.e. acidity > alkalinity
Younger’s Scheme

% of total as mg/L CaCO$_3$

Alkalinity 100%

50%

Acidity 100%

SO$_4^{2-}$ 100%

% Σ (SO$_4^{2-}$+Cl$^-$) meq/L

50%

Cl$^-$ 100%

PUMPED DEEP MINEWATERS

BRINES

NET ACIDIC

NET ALKALINE

POLLUTING DISCHARGES

B R I N E S

PUMPED DEEP MINEWATERS

BRINES

NET ACIDIC

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POLLUTING DISCHARGES

50%

% Σ (SO$_4^{2-}$+Cl$^-$) meq/L

50%

Cl$^-$ 100%

PUMPED DEEP MINEWATERS
Azzie’s Classification

Selection Criteria

- Alkalinity / acidity (Net)

- Salinity
  \[ I = \frac{1}{2} \sum m_i z_i^2 \]

- Metal ion status
  \[ \text{SAR} = \frac{\text{Na}^+}{(\text{Ca}^{2+} + \text{Mg}^{2+})^{\frac{1}{2}}} \]
  or
  \[ \text{AAR} = \frac{(\text{Al}^{3+} + \text{Fe}_{\text{TOTAL}})}{(\text{Ca}^{2+} + \text{Mg}^{2+})^{\frac{1}{2}}} \]
Azzie’s Classification

A = Highly dispersive
B = Highly toxic
C = Highly corrosive
D = Highly scaling

A
B
C
D

DISPERSION
CORROSION
TOXICITY
SCALING

PURE WATER
METAL ION
STATUS
ACIDITY
SALINITY
ALKALINITY

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There are 3 types of drainage produced by sulphide mineral oxidation:

<table>
<thead>
<tr>
<th>Acid Rock Drainage</th>
<th>Neutral Mine Drainage</th>
<th>Saline Drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Acidic pH</td>
<td>- Near neutral to alkaline pH</td>
<td></td>
</tr>
<tr>
<td>- Moderate to elevated metals</td>
<td>- Low to moderate metals. May have elevated Zn, Cd, Mn, Sb, As, or Se</td>
<td></td>
</tr>
<tr>
<td>- Elevated sulphate</td>
<td>- Low to moderate sulphate</td>
<td></td>
</tr>
<tr>
<td>- Treat for acid neutralization and metal &amp; sulphate removal</td>
<td>- Treat for metals &amp; sometimes sulphate removal</td>
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<tr>
<td></td>
<td>- Neutral to alkaline pH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Low metals. May have moderate Fe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Moderate sulphate, magnesium &amp; calcium</td>
<td></td>
</tr>
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<td></td>
</tr>
</tbody>
</table>
What is ML & ARD?

- Metal Leaching & Acid Rock Drainage are *naturally* occurring processes.
- ML & ARD are caused when metal sulphides come into contact with both air and water.
- Rocks at most metal and some coal mines contain sulphide minerals.
- Excavating and crushing of ores greatly increases amount of rock surfaces which can be exposed to oxygen and water.
- So, mining activities can have high potential for leaching acid and metals.
What is ML & ARD?

- ML/ARD can occur from mining wastes (tailings & waste rock), in an open pit or along underground mine surfaces.

- Potential for environmental impacts depends on:
  - Amount of metals in the mine drainage;
  - Amount of acid-neutralizing ability in nearby rocks & water;
  - Amount of dilution available in streams; and
  - Sensitivity of the receiving environment.
Why are ML and ARD important?

- They can have significant negative impacts on the environment if not adequately managed:
  - High levels of metals and/or acid can be harmful or toxic to living organisms;
  - Metals that are absorbed by plants & animals can be passed through food chain.
- Once initiated, it can persist for hundreds of years until sulphides are completely oxidized, and acid and metals are leached from rocks.
- It can be VERY expensive to manage once it has developed
  e.g. BC water treatment plants to treat ML/ARD have cost >$10million (capital), with further $1.5million/yr operating cost.
Mitigation Options 1

- Proper planning of new mining developments can reduce risks, liabilities & costs associated with ML/ARD.
- Geochemical testing of rocks prior to mining can predict the likelihood of ML/ARD being an issue.
- Many strategies are available for prevention and management of ML/ARD.
- Every strategy has strengths and weaknesses, and not all strategies are applicable to all mine sites and their environments.
- For best results, a combination of strategies may be required.
Basic principle behind management strategies:

- Preventing oxygen contact with sulphide minerals
- Reduce amount of water that comes into contact with acid generating wastes to minimize the amount of leaching.

Most commonly used strategies include:

- Avoidance
  *i.e. Don’t mine the sulphide-bearing stuff!*
- Flooding of mine waste materials
  *Timing is crucial …*
- Covers
  *Susceptible to breakdown over time*
- Blending of materials
  *Only successful on a small scale*
- Drainage treatment
  *The last resort!*
Mitigation strategies must be designed to last forever!!

- Mine sites and their environments are dynamic and continue to change long after mining has ceased ..... changes can influence the effectiveness of mitigation strategies over time.

- Regular monitoring, maintenance and responsive management are key to long-term success in preventing impacts from ML/ARD.
Case Studies

Implications of producing large volumes of contaminated water … can mine water be a commodity?

e.g. Coal mines in South Africa
Collieries exploiting the Witbank coalfields in South Africa have to continuously pump water out to reach the coal seams.

Pyrite occurs naturally in coal formations, and when water enters the workings it becomes contaminated.

SA environmental law requires water to be \textit{suitable} for release back into the environment (which may involve management and treatment).

Mines are located in the Upper Olifants catchment, which suffers from a chronic water shortage.

Future mining developments are situated downstream, as is the scenic “Lowveld” and Kruger National Park.

Water is characterized by high Ca, Mg and SO$_4$.
Decided to investigate ways in which contaminated effluent could become a useful resource.

Partnership between ACSA, WRC, Univ Pretoria & Coaltech 2020.

Natural irrigation water varies greatly in quality.

Some common soil problems that may develop:
  - Salinity
  - Water infiltration rate (↑Na & ↓Ca are problematic)
  - Specific ion toxicity (Na, Cl, B)

SACE commissioned three centre-pivot irrigation systems, covering 82ha. Aim was to test viability of irrigating crops with saline effluent, that is high in SO$_4$ and K.
Case Study: Irrigation (South Africa)

- These salts are taken up by certain crops and are highly beneficial if managed correctly.
- Irrigation of prime agricultural soils nearby, using this water, has improved productivity by 300%.
- Further research required:
  - Significance of crop selection
  - Impact of irrigated salts on soil conditions
  - Effects on groundwater
- Significant benefits for small-scale farmers in neighboring communities.
Case Study: Treatment (South Africa)

- The Emalahleni Water Reclamation Project sees the abstraction and treatment of acidic mine water from existing and old mines to a level fit for use by the local municipality.
- Sale of the water allows the mining companies involved to offset the costs of water treatment.
- In 2005, the local municipality was drawing 80-90MLD from Witbank Dam, but this was ~20MLD short of that required.
- A 0.120MLD demonstration plant was built and run for 3 months.
Results from the demonstration plant indicated that:

- pH increased from 2.9 to ~7.
- Total dissolved solids concentration reduced from 4500mg/L to 135mg/L.
- \( \text{SO}_4 \) concentrations reduced from 3500mg/L to 80mg/L.
- A yield of 98% was achieved.

Treated water meets SABS 241 Class 0 Drinking Water Quality Limit.

A full scale plant (20MLD) was commissioned in 2007, and is now fully operational.

The full scale plant draws water from 3 mines, conveys it to a storage facility at treatment site.

Storage facility has capacity for 46MLD, so caters for seasonal fluctuations.
Case Study: Treatment (South Africa)

- Acid water first undergoes neutralization using lime/ limestone.
- This increases pH and allows metals to precipitate out.
- Following clarification water is treated using ultrafiltration to remove remaining metals & bacteria.
- Reverse osmosis using spiral membranes then removes remaining salinity.
- 500 UF membranes and 1200 RO membranes are being used.
Treated water is stored in 10MLD dome-shaped concrete reservoirs before being pumped 9km to the municipal reservoir for distribution to consumers.

Approx 100m$^3$/day of brine and 100t/day gypsiferous waste is produced.

Brine is disposed of in 330,000m$^3$ evaporation ponds.

An on-site laboratory monitors water quality.
Case Studies

Geochemistry to show impact of abandonment and rehabilitation

e.g. Coal mine in South Africa & Pb-Zn mine in Ireland
Case Study: TNDBC (South Africa)

Surface subsidence

Burning u/g workings

AMD

Polluted river
Closure Objectives

Main closure objectives include:

- Physical stability
- Chemical stability
- Biological stability
- Hydrological & hydrogeological environment
- Geographical and climatic influences
- Local sensitivities and opportunities
- Successive land use
- Funds for closure
- Socio-economic considerations
Criteria for Mine Closure

Closure plans:

- Costs included in the assessment of alternatives
- Adopt a risk assessment approach
- Are developed in Mine Planning phase
- Should be maintained during active life of a facility, and routinely updated when modifications are made
- Facilities to be designed to facilitate premature closure
- After-care design should minimize the need for active management
Case Study: New Largo (South Africa)

Does this qualify for a closure certificate?