Biomining in giant mining operations: state-of-the-art and potential for development

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Mining and Environment

Acid Mine Drainage (AMD)
Dr. Bernhard Dold: Treatment, Remediation, and Prevention of Acid-Rock Drainage (ARD)
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\[ \text{FeS}_2 + \frac{7}{2} \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+ \]

Fresh tailings
pH 10

3 months of oxidation
pH 7-8

\[ \text{Fe}^{2+} + \frac{1}{4} \text{O}_2 + \text{H}^+ \leftrightarrow \text{Fe}^{3+} + \frac{1}{2}\text{H}_2\text{O} \]

\[ \text{Fe}^{3+} + 3\text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + 3\text{H}^+ \]

Fe-hydroxide

py
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CT5 Talabre - Chuquicamata

FeS₂ + 14 Fe³⁺ + 8H₂O → 15 Fe²⁺ + 2SO₄²⁻ + 16H⁺
=> FeS₂ + 15/4O₂ + 7/2H₂O → Fe(OH)₃ + 2SO₄²⁻ + 4H⁺
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Acidobacterium-like
Sulfobacillus-like
Acidiphilium sp.
Acidithiobacillus

Leptospirillum, Acidithiobacillus

Gene sequencing and identification

(Diaby et al., 2007)
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**Role of LMWCA in Fe-cycling**

- **pH**
- **Eh**
- Oxidation zone
- Oxidation front
- Neutralization zone
- Primary zone
- Heterotrophs
- Autotrophs
- Fe(III)
- Fe(II)
- LMWCA
- CO₂
- H⁺
- e⁻
- +d

Dold et al. (2005) ES&T
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**Characteristics:**
- Liberation of $\text{Fe}^{2+}$ and $\text{Fe}^{3+}$
- Reduction of $\text{Fe}^{3+}$ and high mobility of ferrous at still neutral pH
- Additional $\text{SO}_4^{2-}$, As, Mo liberation
- Autooxidation when $\text{Fe}^{2+}$-rich solution outcrop in oxidizing environment to $\text{Fe}^{3+}$ and subsequent hydrolysis = > AMD $\text{Fe}, \text{SO}_4^{2-}$-rich

1. **Active AMD plume**
   - Characteristics: oxyanions-rich e.g. $\text{SO}_4^{2-}$ due to Dissolution e.g. anhydrite, gypsum
   - Liberation of Mo and As in the alkaline flotation

2. **Starting oxidation Fe$^{2+}$-rich plume**
   - Characteristics: all neutralization potential is consumed. Sulfate and metal (bi- and trivalent)-rich solutions.

3. **Advanced low pH drainage**
   - Characteristics: all $\text{SO}_4^{2-}$, As, Mo oxidation and hydrolysis = > AMD $\text{Fe}, \text{SO}_4^{2-}$-rich

4. **Secondary AMD plume**
   - Characteristics: all $\text{SO}_4^{2-}$ consumption, sulfate (bi- and trivalent)-rich

**Sulfide oxidation & metal leaching**

- Decades to centuries
- Thousand or millions
- EXOTICA DEPOSITE
- CHUQUICAMATA DEPOSITE
- AMD plume
- LEACHED ZONE
- MINERALIZED GRAVEL
- MINERALIZED BEDROCK
- MINERALIZED GRAVEL
- BARREN GRAVEL
- 6 km
- 4.5 km
- OXIDATION ZONE
- ENRICHED ZONE
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**Goal: Sustainable Mining**

**Mine Waste Management**

- Sulfate Reducing Bacteria (SRB)
  - Leptospirillum
  - Acidithiobacillus
  - Acidiphilium sp.
  - Acidobacteriaceae

**Supergene Enrichment**

- Exploration
  - Increased of Metal recovery
  - Less contamination of CO₂ and SO₂
  - and less energy & water

**Biomining**

- Controlled Management, Prevention, Remediation

**Source**

- Liberation: Oxidation Dissolution
  - Mineralogy, Geology, Geochemistry, Microbiology

- Mobilization
  - Hydrogeology
  - => contamination
    - hydrogeochemistry, hydrodynamic flow

- Retention: Reduction Precipitation Sorption
  - => mineralogy, geology, geochemistry, microbiology

**Sink**
Table 1: Average concentrations of metals in the earth crust with the average concentrations exploited by mining and the enrichment factors. Some concentrations of element still present in mine tailings are shown to highlight the still strong enrichment of these elements in the waste material. Modified after (Evans, 1993).

<table>
<thead>
<tr>
<th>Metal</th>
<th>Ø Crust (%)</th>
<th>Ø by mineral exploitation (%)</th>
<th>Enrichment Factor</th>
<th>Ø In mine tailings</th>
<th>Enrichment Factor tailings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>0.005</td>
<td>0.4</td>
<td>80</td>
<td>0.1 – 0.3</td>
<td>20 - 60</td>
</tr>
<tr>
<td>Ni</td>
<td>0.007</td>
<td>0.5</td>
<td>71</td>
<td>0.2</td>
<td>28.4</td>
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<tr>
<td>Zn</td>
<td>0.007</td>
<td>4</td>
<td>571</td>
<td>2 – 4</td>
<td>275 - 571</td>
</tr>
<tr>
<td>Mn</td>
<td>0.09</td>
<td>35</td>
<td>389</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sb</td>
<td>0.0002</td>
<td>0.5</td>
<td>2500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>0.01</td>
<td>30</td>
<td>3000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>0.001</td>
<td>4</td>
<td>4000</td>
<td>1 - 2</td>
<td>1000- 2000</td>
</tr>
<tr>
<td>Au</td>
<td>0.0000004</td>
<td>0.0001</td>
<td>250</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Dold,2008; RESB)
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(Dold, 2008; RESB)
Conclusions

Biomining in leach dumps in giant Cu mining is extremely ineffective
(70-90 % of the resource remains untouched!)

Criteria for bioleaching is ore grade, NOT mineralogy!!!

Principally only acid soluble Cu is leached

Real bioleaching of chalcopyrite is not reached.

Leach dumps do not have impermeable basement!

Potential

Convince the mining operation that:

1. They can do better (difficult with the actual metal prices!)
2. Characterization of the ore in order to build segregated deposits for optimized recovery
3. To built the deposit in order to increase temperature to reach 50-60°C (thermophile archea)
   4. Additional heat source is needed (pyrite?)
5. Control of Temperature and air flow in the system
6. Control of PLS on long-term
7. Control of secondary mineralogy and chemistry of the solution is needed to prevent precipitation and inhibition
8. Search for additional values in the material and development of extraction techniques