Beyond biorecovery: environmental win-win by Biorefining of metallic wastes into new functional materials

Carmen Falagan
Barry Grail
Barrie Johnson
B³ Project

- Focuses on developing biotechnologies to recover valuable and strategic materials from wastes, generate enriched solids for bio-conversion into new products and to put in place a supply chain for converting waste to product.
**B³ Project Objectives**

• To apply microbial conversion technologies to:

  • Biorecover valuable and strategic materials from wastes.
  • Manufacture high value minerals and nanomaterials from biorecovered products.
  • Evaluate the biogenic nanomaterials in real end user and novel green energy applications
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  - Manufacture high value minerals and nanomaterials from biorecovered products.
  - Evaluate the biogenic nanomaterials in real end user and novel green energy applications
B³ at Bangor University

• Recovery of valuable metals from mine tailings wastes and other mine wastes.
Waste materials

- Mining activities generate large amounts of waste materials with low economic value and high potential to cause damage to the environment.
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  • Are highly-reactive finely ground rock particles that are already processed
Waste materials

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• Metal-mine tailings:
  • Are highly-reactive finely ground rock particles that are already processed
  • may still contain metals (Fe, Cu, Ni, Zn, Ag, Au) and toxic elements (As).
Waste materials

54 – 81 kilotonnes of Cu present in the old flotation tailings
## Mine tailings

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<tbody>
<tr>
<td>BOR</td>
<td>0.13</td>
<td>7.72</td>
<td>6.66</td>
<td>0.04</td>
<td>&lt;</td>
<td>0.21</td>
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River sediments collected at former Zn and Pb mine

River sediments composition (fraction $\phi$ 200-2000 μm)
- Fe ~4.26 %
- Zn ~1.07 %
- Pb ~0.05 %
- Al ~2.28 %

River-head waste pile composition (fraction $\phi$ <200 μm)
- Fe ~2.7 %
- Zn ~2.34 %
- Pb ~0.07 %
- Al ~ 2.22%
Waste materials

• Mining activities generate large amounts of waste materials with low economic value and high potential to cause damage to the environment.

• Metal-mine tailings:
  • Are highly-reactive finely ground rock particles that are already processed
  • may still contain metals (Fe, Cu, Ni, Zn, Ag, Au) and toxic elements (As).

• Acid mine drainage: water with very low pH that normally contains high amounts of dissolved metals and sulfate.
## Mine wastes

- Mine waters: acid mine drainage

<table>
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<tr>
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<th>Redox (mV)</th>
<th>pH</th>
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<td><strong>Parys Mountain</strong></td>
<td>~700</td>
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<td>42</td>
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Mine wastes

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Possible economical value:

- Flow 1.4-12.7 L/sec → 59-533 mg/L of Cu per sec
- 7.2 Kg – 585 Kg of Cu per day
- 48.6 – 3949 USD/day
Mine wastes

- Mine waters: acid mine drainage

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<th>Source</th>
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**Source of pollution**

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<th>Source</th>
<th>pH (mg/L)</th>
<th>Fe (mg/L)</th>
<th>As (mg/L)</th>
<th>Al (mg/L)</th>
<th>Zn (mg/L)</th>
<th>Mn (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheal Jane</td>
<td>3.0</td>
<td>63.66</td>
<td><strong>1.5</strong></td>
<td>9.45</td>
<td><strong>22.24</strong></td>
<td>35.17</td>
</tr>
</tbody>
</table>

- **Redox (mV)** values are indicative of oxidative conditions in the environment.
- **pH** values below 7 indicate acidity, which can be harmful to aquatic life.
- **Cu**, **Fe**, **Zn**, and **Mn** are heavy metals typically found in mine waters.
- **As** and **Al** are other elements that can affect water quality.
## Mine wastes

- **Mine waters: acidic mine pit lakes**

<table>
<thead>
<tr>
<th>Pit lake IPB</th>
<th>Depth</th>
<th>pH</th>
<th>Redox</th>
<th>Fe\textsubscript{total}</th>
<th>SO\textsubscript{4}^{2-}</th>
<th>Zn</th>
<th>Cu</th>
<th>As</th>
<th>Mn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake 1</td>
<td>6</td>
<td>2.6</td>
<td>+844</td>
<td>546</td>
<td>620</td>
<td>17</td>
<td><strong>3.9</strong></td>
<td>0.045</td>
<td>17</td>
<td>109</td>
</tr>
<tr>
<td></td>
<td>10.5</td>
<td>3.0</td>
<td>+577</td>
<td>752</td>
<td>1215</td>
<td>31</td>
<td>1.7</td>
<td>0.092</td>
<td>30</td>
<td>126</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>4.5</td>
<td>+304</td>
<td>4910</td>
<td><strong>3990</strong></td>
<td>95</td>
<td>0.03</td>
<td><strong>14.650</strong></td>
<td>110</td>
<td>70</td>
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<tr>
<td>Lake 2</td>
<td>7</td>
<td>2.9</td>
<td>+765</td>
<td>45</td>
<td>870</td>
<td>68</td>
<td>21</td>
<td>0.021</td>
<td>17</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>2.7</td>
<td>+697</td>
<td>205</td>
<td>1355</td>
<td>109</td>
<td>26</td>
<td>0.240</td>
<td>118</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>4.2</td>
<td>+333</td>
<td>7600</td>
<td><strong>7405</strong></td>
<td>305</td>
<td>1</td>
<td>0.170</td>
<td>394</td>
<td><strong>151</strong></td>
</tr>
<tr>
<td>Lake 3</td>
<td>5</td>
<td>2.8</td>
<td>+869</td>
<td>153</td>
<td>n.a.</td>
<td>65</td>
<td>17</td>
<td>0.055</td>
<td>31</td>
<td>120</td>
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<tr>
<td></td>
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<td>2.7</td>
<td>+879</td>
<td>197</td>
<td>n.a.</td>
<td>101</td>
<td>26</td>
<td>0.072</td>
<td>51</td>
<td>161</td>
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<tr>
<td></td>
<td>90</td>
<td>2.8</td>
<td>+680</td>
<td>212</td>
<td>n.a.</td>
<td>120</td>
<td><strong>28</strong></td>
<td>0.028</td>
<td>67</td>
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Bioleaching of mine wastes:
Tailings
River sediments

Consortium of acidophilic iron and iron/sulfur oxidizing bacteria

Elemental sulfur

Tailings or river sediments (5% w/v)
SULFUR ENHANCED BIOLEACHING

- 2.0 L ABS/TE
- Pulp density 5% (w/v)
- 0.5% (w/v) sulfur
- Non-controlled pH and at 45°C

Effective method to extract copper

CLC

- Cu: 31%, 32%, 84%
- Zn: 43%, 36%, 37%
- Ag: 0%, 8%, 2%

BOR

- Cu: 55%, 55%, 90%
- Zn: 59%, 54%, 99%

30°C/pH 1.7/aerobic 45°C/pH 1.7/aerobic 45°C/pH 1.8-1.0/aerobic → anoxic
SEB tailings: possible economic value

- Cobre Las Cruces → Copper.
  - Produces 1.5 million of tonnes/year of tailings (10.8 kilotonnes/year of copper)
  - If 84% of copper is leached → ~ 42 million USD/year.
SEB tailings: possible economic value

- Cobre Las Cruces → Copper.
  - Produces 1.5 million of tonnes/year of tailings (10.8 kilotonnes/year of copper)
  - If 84% of copper is leached → ~ 42 million USD/year.

- Bor → Copper.
  - 54 – 81 kilotonnes of Cu present in the old flotation tailings.
  - If 90% of copper is leached → ~ 217 – 337 million USD.
Meeting with a mining company: outcome

- Advantages of bioleaching:
  - The concentration of Cu in tailings is high.
  - The tailings are already processed.
  - Bioleaching of recalcitrant materials
Meeting with a mining company: outcome

• Problem 1
  • The copper grade is high → no need of re-processing the tailings
Meeting with a mining company: outcome

- **Problem 1**
  - The copper grade is high → no need of re-processing the tailings

- **Problem 2: Retention times**
  - Raw material to product → 7 days
Meeting with a mining company: outcome

• Problem 1
  • The copper grade is high → no need of re-processing the tailings

• Problem 2: Retention times
  • Raw material to product → 7 days
  • Bioleaching of tailings → minimum of 20 days to get more than the 50% Cu leached. Add process of PLS.
Other material bioleached

River sediments collected at former Zn and Pb mine

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Total metals bioleached from river sediments:

- Fe 41.22 %
- Zn >99 %
- Mn >99 %
- Al 24.37 %
- Pb 1.52 %

(PbS expected to be leached but forms anglesite; PbSO$_4$)
Total metals bioleached from river sediments:

- Fe 41.22 %
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Metal with low economic value:

Zn: 3.2 USD/Kg
Al: 2.07 USD/Kg
Mn: 4.54 USD/Kg

(compared to for example Co: 61.6 USD/Kg)

Low economic value, but it could be used as low-cost bioremediation approach
Selective precipitation of Cu and Zn by using biogenic H₂S from mine waters

• Off-line: a metal-containing solution is bubbled with H₂S, metal will precipitate as their sulfide forms.

• In-line: a metal-containing solution is passed through a sulfidogenic bioreactor. Metals will precipitate as their sulfide (e.g. Cu, Zn) forms or, at pH>5, as hydroxysulfate (e.g. Al)
Selective precipitation of Cu and Zn by using biogenic H$_2$S from mine waters

- Off-line
Off-line precipitation of Cu

>99% copper is recovered as Cu sulfide ($$).
Off-line precipitation of Zn

- ZnS quantum dots ($$) absorb certain wavelengths of light and emit in close absorption wavelength of chlorophyll.
Off-line precipitation of Zn

ZnS quantum dots: can be generated in a very short period of time.

\[ + \text{H}_2\text{S} \]
Off-line precipitation of Zn

ZnS quantum dots  PROBLEM: need to be free of other metals.
Off-line precipitation of Zn

**ZnS quantum dots:** AMD cannot be used as there are many other metals dissolved in the water.
But we can use this technology for low-cost bioremediation
Selective precipitation of Cu and Zn by using biogenic H$_2$S from mine waters: bioremediation

- Off-line: already seen it in the last slides.
- In-line
Selective precipitation of Cu and Zn by using biogenic H$_2$S from mine waters: bioremediation

- Off-line
- In-line
In-line precipitation of metals

Bioreactor populated by sulfate reducing bacteria:

Operated at 20 °C.

Operated at pH 5.5

Use glycerol (cheap substrate, by-product of biodiesel) as carbon and energy source.

Rich-metal water coming into the reactor.

Metal-free water coming out.
Bioremediation

In-line precipitation of metals

Successful removal of Zn and Al, the main two metals in the water.
Bioremediation

In-line precipitation of metals

• Biosulfidogenesis can be used to remove metals in mine waters.

• The methodology developed represents an effective low-cost strategy for metal recovery and mine waste treatment and should be considered as a more environmentally-benign alternative to chemical treatment of mine waters.
Bioremediation

In-line precipitation of metals

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New approaches for extracting and recovering metals from mine tailings

Carmen Falagán *, Barry M. Grail, D. Barrie Johnson

College of Natural Sciences, Bangor University, Denision Road, Bangor LL57 2UW, UK

The effects of temperature and pH on the kinetics of an acidophilic sulfidogenic bioreactor and indigenous microbial communities

Ana Laura Santos, D. Barrie Johnson *

College of Natural Sciences, Bangor University, Bangor LL57 2UW, UK

Biologically-induced precipitation of aluminium in synthetic acid mine water

Carmen Falagán a,⁎, Iñaki Yusta b, Javier Sánchez-Espeña c, D. Barrie Johnson a

a College of Natural Sciences, Bangor University, Denision Road, Bangor LL57 2UW, UK
b Departamento de Mineralogía y Petrología, Facultad de Ciencia y Tecnología, University of the Basque Country (UPV/EHU), Apdo. 644, 48080 Bilbao, Spain
c Instituto Geológico y Minero de España, C/ la Calera 1, 28760 Tres Cantos (Madrid), Spain
A modular continuous flow reactor system for the selective bio-oxidation of iron and precipitation of schwertmannite from mine-impacted waters

Sabrina Hedrich *, D. Barrie Johnson
School of Biological Sciences, Bangor University, Bangor LL57 2UW, UK

Remediation and Selective Recovery of Metals from Acidic Mine Waters Using Novel Modular Bioreactors

Sabrina Hedrich*† and D. Barrie Johnson
School of Biological Sciences, College of Natural Sciences, Bangor University, Deiniol Road, Bangor LL57 2UW, United Kingdom
Thank you very much

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Angela Murray
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Sophie Archer

Hylke Glass
Bethany Colgan