Using phosphate in mining wastes is nothing new! It worked! Why didn’t the previous work take off?

**ECONOMICS**
- Refined, costly phosphate material
- Transportation cost
- Cost of application

**MODE OF APPLICATION**
- Mixing into tailings at about 5%
- Coating surfaces with P
- Encapsulating with P

### Prevention of acid generation
- Where does it need to take place?
  - On the mineral surface, as a result of oxidation and microbial activity, metals are liberated such that they become water soluble
  - This process is similar to corrosion
  - Corrosion protection is achieved through phosphate coating

### The different approach: Integrated into the mining waste generation process
Application of phosphate with focus on the contaminant generating process – work inside the wastes
- Test if it works in the field over a long time
- Test in “high quality” acid mine drainage
- Examine the causes of the improvement once it has practical results in the field

### WHY so many sites the same thing?
- Selbaie: pilot test system and lab tests
- Devco: coal – field tests and coarse waste rock tests
- Buchans: water reactions - solute phosphate (buffering) and solids reactions in neutral and acidic AMD
- Comparative leaching of other phosphate mine material
  - South bay: sequential extractions on tailings
Ecol engineering principle

Change the habitat conditions and thereby the forcing function is altered.

This principle applied to the mineral surface oxidation – and with the assumption that Fe III and metals are indeed the main forcing function.

It would follow that by:

- adding a reactant(s) to the water which is then transported to the weathering site on the mineral surface – the forcing function would be changed.
- the reactant should contain essential elements to microbial growth, then the habitat would be altered – to allow other microbial groups to colonize.

Does the colonization step require the presence of some organic carbon in the form of dormant chemolithotrophs?

If this is roughly reasonable – then it would explain the effects of the NPR on the rocks and in the tailings?

Composition of NPR – nutrients

Why a waste product – large problem – economics
Why a secondary mineral of phosphate – weathering ability rain water
Why containing P – chemistry and nutrient supply is appropriate

Waste rock piles- dissolve P in rainwater to react on rock surfaces inside pile

Waste Rock Drum Experimental Setup

© by Authors and IMWA
SEM and X-ray scan of surface of pyritic waste rock treated with phosphate rock

Figure 4. Stained thin sections of the biofilms formed in the pH 2.2 and 7.2 system after 73 days (A and B, respectively). (A): The biofilm was composed of cells (a), very fine precipitates trapped in an exopolymer-like matrix (b) and detrital fragments from the rock surface (c). (B): cell (a) surrounded by secondary precipitates trapped in extracellular material (b) and detrital fragments from the rock surface (c).
Boojum's projects with NPR were carried out in the field. The results had to work in the field first! The company's interest as to why it worked was limited.

Result: pictures and data; science later.

### Buchans Tailings/Concentrate

Elemental concentration of Phosphate Rock and Tailings

<table>
<thead>
<tr>
<th>Element</th>
<th>Phosphate Rock Long Harbour Sand</th>
<th>Tailings/concentrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>7435</td>
<td>1800</td>
</tr>
<tr>
<td>Cu</td>
<td>34</td>
<td>420</td>
</tr>
<tr>
<td>Fe</td>
<td>5130</td>
<td>24800</td>
</tr>
<tr>
<td>K</td>
<td>1201</td>
<td>360</td>
</tr>
<tr>
<td>Mg</td>
<td>2736</td>
<td>1600</td>
</tr>
<tr>
<td>Mn</td>
<td>59</td>
<td>46</td>
</tr>
<tr>
<td>Na</td>
<td>555</td>
<td>100</td>
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<tr>
<td>Np</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>113987</td>
<td>50</td>
</tr>
<tr>
<td>Pb</td>
<td>48</td>
<td>92</td>
</tr>
<tr>
<td>S</td>
<td>6693</td>
<td>1100</td>
</tr>
<tr>
<td>Si</td>
<td>104</td>
<td>M4</td>
</tr>
<tr>
<td>Sr</td>
<td>935</td>
<td>270</td>
</tr>
<tr>
<td>Zn</td>
<td>95</td>
<td>1600</td>
</tr>
</tbody>
</table>

### Methods

- Set up in open buckets (top and bottom) with different phosphate:tailings ratios. Exposure in the field started in June 1999.
- 3 buckets (2, 3, and 7) remained exposed in field until 2002.
- After 10 days settling in field, shipped to laboratory for measurements.
- Buckets 1, 4, 5, and 6 to laboratory.
- Exposure in fridge - saturated 40 g of phosphate tailings and 200 ml of distilled water.
- Comparison of field exposed and fridge saturated samples.
Acidity Generated over Time (mg/L/month) for Tailings/Phosphate Rock Mixes

<table>
<thead>
<tr>
<th>LAB</th>
<th>Days</th>
<th>Control</th>
<th>1</th>
<th>Control</th>
<th>2</th>
<th>1:4</th>
<th>#1</th>
<th>1:4</th>
<th>#4</th>
<th>1:8</th>
<th>#5</th>
<th>1:12</th>
<th>#6</th>
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<tbody>
<tr>
<td></td>
<td>0-112</td>
<td>95.4</td>
<td>345</td>
<td>-4.9</td>
<td>9.8</td>
<td>5.2</td>
<td>-0.0</td>
<td>3.0</td>
<td>7.2</td>
<td>5.4</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>112-514</td>
<td>13.6</td>
<td>320</td>
<td>0.03</td>
<td>3.0</td>
<td>7.2</td>
<td>5.4</td>
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<tr>
<td></td>
<td>514-830</td>
<td>4.0</td>
<td>309</td>
<td>-1.4</td>
<td>1.0</td>
<td>0.2</td>
<td>-1.2</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>830-1147</td>
<td>10.9</td>
<td>655</td>
<td>-0.6</td>
<td>5.4</td>
<td>3.3</td>
<td>0.2</td>
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FIELD STORAGE

<table>
<thead>
<tr>
<th>Days</th>
<th>1:8</th>
<th>#2</th>
<th>1:12</th>
<th>#3</th>
<th>1:20</th>
<th>#7</th>
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<tr>
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<td>124</td>
<td>61.3</td>
<td>-55.3</td>
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<td></td>
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<tr>
<td>27-67</td>
<td>-27.0</td>
<td>24.0</td>
<td>0.4</td>
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<td></td>
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</tbody>
</table>

Elemental concentration of pore water after phosphate mixed into tailings (1147 d)

<table>
<thead>
<tr>
<th>Element (mg/L)</th>
<th>Control</th>
<th>1</th>
<th>2</th>
<th>#1</th>
<th>#4</th>
<th>#5</th>
<th>#6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>64</td>
<td>140</td>
<td>0.17</td>
<td>6.6</td>
<td>24</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>12</td>
<td>160</td>
<td>0.022</td>
<td>0.15</td>
<td>0.51</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>4.2</td>
<td>2600</td>
<td>0.052</td>
<td>0.19</td>
<td>0.14</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>43</td>
<td>120</td>
<td>61</td>
<td>33</td>
<td>41</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>13</td>
<td>290</td>
<td>9</td>
<td>51</td>
<td>28</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>&lt;0.05</td>
<td>1.5</td>
<td>&lt;0.05</td>
<td>0.07</td>
<td>0.37</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>870</td>
<td>5800</td>
<td>480</td>
<td>510</td>
<td>510</td>
<td>480</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>35</td>
<td>74</td>
<td>11</td>
<td>38</td>
<td>47</td>
<td>39</td>
<td></td>
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<tr>
<td>P</td>
<td>&lt;0.05</td>
<td>1.5</td>
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<td>Si</td>
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<tr>
<td>Zn</td>
<td>35</td>
<td>74</td>
<td>11</td>
<td>38</td>
<td>47</td>
<td>39</td>
<td></td>
</tr>
</tbody>
</table>

Coarse coal waste : lime compacted etc., and NPR
Hard pan top view

Precipitate contained:
Ca, Al, Fe, Cu, P and Zn

RESULT: LIMING INDUSTRY DISLIKED IT

© by Authors and IMWA
Tailings Surface Cover Development through Integration of Reactive Phosphate and Organic Matter
Measurements on lab-stored samples

Publications

Inhibition with phosphate


Publications

Precipitate with phosphate


© by Authors and IMWA
Assumptions made for the field work

The corrosion process on metal is the same or similar to that on the rocks or on mineral surfaces. Reasonable?

The first weathering step acidifies the mineral surface colonization by Chemolithotrophs takes place. Why do they not form biofilms?

Release of iron in contact with oxygen – change in redox – induction of microbial Starvation-Survival mode – drying leads to changing conditions on the mineral surface and revival of microbial activity, so moisture further leaching results in ARD or AMD. Does this make sense?

AMIRA project – 1st Progress report

AMIRA P933 Process oriented investigation on passive treatment systems

Objectives

i) critical assessment of currently available passivation technologies → inhibit or slow sulfide oxidation in mine waste rock and tailings for management of acid rock drainage (ARD).

ii) short term effectiveness evaluation with a complete understanding of the reaction mechanisms and stability of the products

Program 5: Ecological Engineering (Biological Remediation) with Both Organic Waste and Phosphate Additions

(in Collaboration with Boojum Research, Canada)

Boojum send NPR Rocks to Australia

First Findings P933 AMIRA

Control Samples

Low pyrite

High pyrite

Second Findings P933 AMIRA

Toward understanding biofilm initiating factors

What are the conditions needed to give the stimulus for the start of growth?

Where does the process start on the mineral surface?

What was it that started the biofilm?

Did the biofilm originate from NPR particles, which fell or were transported with the first years fall rains throughout the drum?

Can one of these particles fall into a corrosion pit and start the biofilm?

Are the metabolic products of the "phosphate mining" microbes the nutrient source of the oxidation reduction biofilm?

How does rain water to path through a waste rock pile?
WHY so many sites the same thing?

- Selbaie
  - pilot test system and lab tests
- Devco
  - coal – field tests and coarse waste rock tests
- Buchans
  - water reactions- solute phosphate (buffering) and solids reactions in neutral and acidic AMD
  - Comparative leaching of other phosphate mine material
  - South bay: sequential extractions on tailings

I believe focused field work is needed

Concurrent process understanding site specific

Suppression of Sulphide Mineral Oxidation in waste Rock and Tailings – anyone has a waste rock pile?

1. Scoping the sulphate challenge
2. Consolidate existing Boojum data and new literature – ongoing
3. Assess the durability of the sulphides inhibition technique – IMWA paper
4. Establish the universality and optimize the process – ICARD paper

OXIDATION RATES – log r – drastic diff.

Williamson and Rimstidt, 1994

\[
\log r = 10^{-19.71(\pm 0.86)} + 12.93(\pm 1.04)\log(Eh)
\]

\[
\log r = 10^{-19.71(\pm 0.86)} + 12.93(\pm 1.04)\log(Eh)
\]

Control vs NPR