LOCATING ORE UNDERCOVER USING A BACTERIAL LEACH AND OTHER GEOCHEMICAL TECHNIQUES

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Extraction Techniques

• Various methods have been employed
  – Some are novel: enzymes, buffers
  – Some are recycled: new technology with old methods
• Many extractions are not compared to other techniques
Bacterial Leach

- Developed by Curtin University, now run by SoLogic Ltd and called LocatOre®
  - Uses a non-pathogenic bacteria for the dissolution of the ultra thin surface layers of minerals
  - Advantages
    - Simple technique
    - Geochemical signature is not diluted in the matrix
  - Disadvantages
    - Lack of knowledge about the quantification/selectivity of individual elements
    - Bacteria are saturated quickly, incomplete digestion requires combining elements in suites to enhance signature
Background Problem

• Leviathan Gold Mine (Stawell) is interested in less expensive and intrusive methods to target mineralised zones
  – Western Victorian Gold deposits are known to repeat under cover to the north
• MPI (now Lionore) also had sampled soil over buried Ni deposit (Honeymoon Well)
  – Opportunity to test Bacterial Leach in another environment
Honeymoon Well

Location of research

Mineral deposits and geology of HW (Dept. Industry and Resources WA, 2003)
Honeymoon Well
OBJECTIVES

• Assess the efficacy of the Bacterial Leach in locating mineralisation under cover in Victoria and WA
• Compare Bacterial Leach to other techniques
METHODS

• Initial development at Kewell
• Sites investigated
  – Stawell (Wildwood): six traverses, across a known VMS Au deposit, with 20-70 m of alluvial cover
    • 80 soil samples at 30 m intervals from argillic horizon
  – Honeymoon Well: three traverses across a known Ni ore body
    • 45 soil samples, 15 from each traverse, at 20-50 m intervals from surface and approximately 35 cm depth
  – Kewell: Regolith profiles sampled at 5 m intervals down hole
## Analytical Techniques

<table>
<thead>
<tr>
<th>Analytical Method</th>
<th>Target phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolution</td>
<td>None. All phases incorporated. Useful in understanding background soil composition and interpretation of leach results.</td>
</tr>
<tr>
<td>Bacterial Leach</td>
<td>Non-selective, surface sorbed elements</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>Water-soluble and exchangeable/surface sorbed elements</td>
</tr>
<tr>
<td>Ammonium acetate</td>
<td>Carbonate bound elements</td>
</tr>
<tr>
<td>0.1M Hydroxylamine hydrochloride in 0.01 M nitric acid</td>
<td>Amorphous/weakly crystalline Mn oxide bound elements</td>
</tr>
<tr>
<td>0.25M Hydroxylamine hydrochloride in 0.25 M nitric acid at 60ºC</td>
<td>Amorphous/weakly crystalline Fe oxide bound elements</td>
</tr>
</tbody>
</table>

- All analysis run on ICP-MS/AES for a suite of approximately 50 elements
Statistical Techniques

- Correlation between elements based on laboratory techniques
- Principal Component Analysis
- Hypergeometric statistics to assess anomaly expression
  - Allows orientation survey results to be statistically compared based on probability of response through random number generation
  - Requires assumptions of expected anomalous sample points prior to getting results
  - Removes bias of viewer (Stanley 2003; Stanley and Noble 2005)
RESULTS

- Wildwood Site 1 = All listed analyses
- Honeymoon Wells = Bacterial Leach and Totals
- Kewell = Weak HA and some Totals
- Bacterial Leach uses elements suites that are combinations of Ni, Cu, As, Sb, Ga, Ge, Se, W, Te, Bi, V, Cr, Ti
- Most element suites respond similarly
Element Suite Responses

![Graph showing Element Suite Responses](image)
Site 1 Wildwood
Questionable Success

• No consistent single element anomalous results for Bacterial Leach
• Not successful in 3 traverses
• Traverse #3 was not assessed as underlying mineralisation is being revised
• Combining selected element suites was successful (confirmed with hypergeometrics) in 2 of 5 traverses corresponding to the shallowest region of cover in the prospect.
Hypergeometric evaluation

- $Pr(x) = 3$ traverse 6 by chance = 2%
- $Pr(x) = 3$ traverse 5 by chance = 3.5%
- Add negative response $Pr(x) \geq 2 = 16\%$ for traverse 6
Wildwood Hypergeometric Evaluation

<table>
<thead>
<tr>
<th>Traverse</th>
<th>Sample points</th>
<th>True positive</th>
<th>False positive</th>
<th>False negative</th>
<th>Hypergeometric Probability P(x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
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<td>0</td>
<td>5</td>
<td>100</td>
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<tr>
<td>4</td>
<td>16</td>
<td>0</td>
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<td>4</td>
<td>100</td>
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<tr>
<td>5</td>
<td>13</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>3.5</td>
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<tr>
<td>6</td>
<td>11</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Wildwood Technique Evaluation

<table>
<thead>
<tr>
<th>Technique</th>
<th>Successful analysis P(x) &lt; 0.05</th>
<th>Number of orientation surveys</th>
<th>Technique % success rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolution</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td><strong>Bacterial Leach</strong></td>
<td><strong>2</strong></td>
<td><strong>5</strong></td>
<td><strong>20</strong></td>
</tr>
<tr>
<td>0.1M HA</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>0.25M HA</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Ammonium chloride</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Ammonium acetate</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>EC</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>pH</td>
<td>0</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
Site 2 Honeymoon Well
Unsuccessful Exploration

Geochemistry

• Single element anomalies occur, but do not correspond with mineralised zones
• Combining selected elements did not produce a significant trend in Bacterial Leach
• Values for elements taken at depth were much higher than surface samples for Bacterial Leach
Comparison of sample depth – Bacterial Leach

- Enrichment Factors significantly higher in samples taken 30 cm lower in the profile
- Average EF for elements at depth 4.3 x
- Very important to sample consistently and on morphology
- Be aware of erosional/depositional landforms
Comparison of sample depth - Totals

- Total Digestion
  - Enrichment Factors slightly higher in samples taken 30 cm lower in the profile
  - Average EF for elements at depth 1.2 x
Advantage of partial/selective extractions

Bacterial Leach geochemical suite response

Bacterial Leach Cu and Zn concentrations

Total Dissolution Cu and Zn concentrations

NH$_2$OH HCl Cu and Zn concentrations
Why the poor results?

• Different climate and soil type (influence of soil properties)
• Different target ore
• Understanding dispersion direction and mechanisms of movement and anomaly formation
• Lack of understanding about technique
Comparison of techniques using Stawell samples (Wildwood, Kewell and Wartook)

- Correlation analysis to understand the different results from the different techniques
- PCA analysis
## Correlation of techniques

### Bacterial Leach versus total digestion

<table>
<thead>
<tr>
<th></th>
<th>Li T</th>
<th>As T</th>
<th>Cu T</th>
<th>Zn T</th>
<th>V T</th>
<th>Cr T</th>
<th>Mn T</th>
<th>Ni T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial Leach</td>
<td>-0.18</td>
<td>-0.20</td>
<td>0.23</td>
<td>-0.24</td>
<td>-0.24</td>
<td>-0.51</td>
<td><strong>0.94</strong></td>
<td>-0.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Rb T</th>
<th>Sr T</th>
<th>Zr T</th>
<th>Cd T</th>
<th>Sb T</th>
<th>Te T</th>
<th>Ba T</th>
<th>Pb T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial Leach</td>
<td>-0.52</td>
<td><strong>0.90</strong></td>
<td>-0.37</td>
<td><strong>0.80</strong></td>
<td>-0.40</td>
<td>0.13</td>
<td>0.12</td>
<td>0.29</td>
</tr>
</tbody>
</table>

### Bacterial Leach versus hydroxylamine hydrochloride

<table>
<thead>
<tr>
<th></th>
<th>Li HA</th>
<th>As HA</th>
<th>Cu HA</th>
<th>Zn HA</th>
<th>V HA</th>
<th>Cr HA</th>
<th>Mn HA</th>
<th>Ni HA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial Leach</td>
<td><strong>0.92</strong></td>
<td>0.73</td>
<td><strong>0.95</strong></td>
<td><strong>0.89</strong></td>
<td>0.80</td>
<td>0.33</td>
<td><strong>0.96</strong></td>
<td>0.70</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Rb HA</th>
<th>Sr HA</th>
<th>Zr HA</th>
<th>Cd HA</th>
<th>Sb HA</th>
<th>Te HA</th>
<th>Ba HA</th>
<th>Pb HA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacterial Leach</td>
<td><strong>0.91</strong></td>
<td>0.97</td>
<td>0.69</td>
<td><strong>0.87</strong></td>
<td>0.67</td>
<td><strong>0.89</strong></td>
<td>0.58</td>
<td><strong>0.85</strong></td>
</tr>
</tbody>
</table>

- **Strong Correlation**
- **Moderate Correlation**
- **Moderate Correlation**
- **Weak Correlation**

Indicates Bacterial Leach may be phase selective
• Principal Component Analysis
  – Confirms correlation analysis about similarity of techniques and geochemical response
Transported regolith component loadings

Residual regolith component loadings

- Technique responses between elements do not vary greatly depending on change in regolith
The 3D test of faith

- Do you see the distribution in 3D?
- Bacterial Leach too expensive as a first test
- Hydroxylamine Hydrochloride (and Totals) used
- Results: No clear dispersion pattern to surface
Arsenic values above Au mineralisation
Arsenic values above barren sulphides

<table>
<thead>
<tr>
<th>150</th>
<th>100</th>
<th>50</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.64</td>
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<tr>
<td>0.72</td>
<td>1.64</td>
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<tr>
<td>0.99</td>
<td>3.06</td>
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<tr>
<td>0.05</td>
<td>0.62</td>
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<tr>
<td>1.92</td>
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<td>0.31</td>
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<td>0.10</td>
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<td>0.31</td>
<td>1.79</td>
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<td>0.71</td>
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<td>15.31</td>
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<td>13.41</td>
<td>7.48</td>
<td>13.41</td>
<td>13.41</td>
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<tr>
<td>2.21</td>
<td>3.88</td>
<td>2.21</td>
<td>2.21</td>
</tr>
</tbody>
</table>

CRCLEME
However...

- Ratio of pathfinders with Mn revealed a zone of sampling interest
- Capillary fringe/Watertable regolith samples
  - Relates to calcrete, base of hardpan, interface sampling
  - Zone of intense chemical changes and movement and element capture
Similar response from Pb and Zn

Cu, Ni and Co response evident, but less pronounced
CONCLUSIONS

• Understanding sample media, depth and soil properties are key to getting good results
  – Depth is clearly critical at Honeymoon Well
  – Potentially new sampling zone detected at Stawell

• Hypergeometric statistics provide a method to compare techniques

• Understanding movement/dispersion mechanisms is essential to future geochemical investigation undercover
CONCLUSIONS

• Bacterial Leach and the other analyses provided different results to each other
• Bacterial Leach does seem to have some association with Mn-oxide bound elements (HA technique)
• No method consistently identified mineralisation beneath thick cover, although Bacterial Leach was the only successful technique
• Bacterial Leach has not proved superior to the other techniques at this stage, but the element suites and increased contrast for anomalies may be beneficial
Thank you for your attention

Thanks also to the following groups:

CRC LEME
CSIRO Exploration and Mining
Curtin University of Technology
Leviathan Resources
LionOre
Questions?