PHYTOMINING METHOD APPLICATION IN GOLD MINING

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1. INTRODUCTION TO PHYTOMINING

1.1 Background

- Conventional mining (mechanical equipment) impacts on the environments
- Abundant amount of low-grade ores (gold)
- Low cost mining and gold prices
- Remarkable ability of plants to accumulate metals
- Industrial synergies

1.2 Goal

- Introducing phytomining method
- Reducing poor environmental consequences of mining
- Maximising ore (gold)

Figure 1. Conventional Mining

Figure 2. Gold Price Trend
Source: [http://goldprice.org/gold-price-australia.html](http://goldprice.org/gold-price-australia.html)
[Accessed 11 May 2017]
1.3 Terminology and Definitions

Phytoextraction is to extract metal from soil substrate where plants capable of growing in high mineral environments (Chaney et al., 1998)

Phytomining of gold involves extracting gold from soil substrates by harvesting specially selected hyper-accumulating plants (Sheoran, S., Sheoran, & Poonia, 2013)

Figure 2 Plants Accumulate Metals

Source:
https://motherboard.vice.com/de/article/phytomining
[Accessed 10 May 2017]
2. METHODS COMPARISON

Phytomining

- SCALE: Small scale mining
- EQUIPMENT: Hyperaccumulating plants and chemical substances
- ECONOMIC BENEFIT: Depends on metal concentration and are covered
- CAPITAL INVESTMENT: Low capital investment
- ENVIRONMENT IMPACT: Less environment impact
- MINERAL ORE DEPOSIT: Surface ore, or mineralised soil
- FUTURE RELIABILITY: It is promising method and green approach for mining

Conventional Mining

- SCALE: Large scale mining application
- EQUIPMENT: Sophisticated mining equipment
- ECONOMIC BENEFIT: High economic benefit
- CAPITAL INVESTMENT: Huge capital investment
- ENVIRONMENTAL IMPACT: Intermediate to significant impact
- MINERAL DEPOSIT: Primary deposit, deep reserve
- FUTURE RELIABILITY: Depends on exploration and Resources condition
### 3. PHYTOMINING RESEARCH PROJECTS

**Table 1: Example Plant Species Which Hyperaccumulate Elements**

<table>
<thead>
<tr>
<th>Element</th>
<th>Plant Species</th>
<th>Max. Conc. (mg/kg dry wt)</th>
<th>Location Collected</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>As</td>
<td><em>Pteris vittata</em></td>
<td>22,300</td>
<td>Florida</td>
<td>Ma et al. (2001)</td>
</tr>
<tr>
<td>Cd</td>
<td><em>Noccaea caerulescens</em></td>
<td>2,910</td>
<td>France</td>
<td>Reeves et al. (2001)</td>
</tr>
<tr>
<td>Co</td>
<td><em>Phyllantus favieri</em></td>
<td>8,050</td>
<td>United States</td>
<td>van der Ent (unpubl.)</td>
</tr>
<tr>
<td>Ni</td>
<td><em>Phyllanthus serpentinus</em></td>
<td>38,100</td>
<td>New Caledonia</td>
<td>Kersten, Brooks, Reeves, and Jaffré (1979)</td>
</tr>
<tr>
<td>Se</td>
<td><em>Astragalus racemosus</em></td>
<td>14,900</td>
<td>Wyoming</td>
<td>Beath, Epsom, and Gilbert (1937)</td>
</tr>
<tr>
<td>Tl</td>
<td><em>Biscutella laevigata</em></td>
<td>15,200</td>
<td>France</td>
<td>Anderson et al. (1999)</td>
</tr>
<tr>
<td>Zn</td>
<td><em>Noccaea caerulescens</em></td>
<td>39,600</td>
<td>Germany</td>
<td>Reeves and Brooks (1983)</td>
</tr>
</tbody>
</table>

Source: (Chaney & Baklanov, 2017)
4. PHYTOMINING TECHNOLOGY

UNDERSTANDING OBJECT
Collecting information of metal and its properties as well as plant behaviour toward chemical

COLLECTING INFORMATION
Gathering relevant information that can support the study of phytomining in gold metal

ANALYSING INFORMATION
Filtering and Concluding related information and then, synthesising previous research to be develop

INTERDISCIPLINE COORDINATION
Mining, Environment, Metallurgy, Biology, and Genetic Engineering

LOREM IPSUM
Lorem ipsum dolor sit amet
4.1 Factor Influencing Phytomining

Factors

- Plants associated
- Hyperaccumulating plants

Soil associated

- Soil pH
- Fertilizer
- Chelates

Source: (Sheoran et al., 2013)
Table 2: Hyperaccumulator Plants for various metal

<table>
<thead>
<tr>
<th>Element</th>
<th>Lower limit for hyperaccumulation (mg/kg)</th>
<th>No. of hyperaccumulators</th>
<th>Families of hyperaccumulators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>1000</td>
<td>5</td>
<td>Pteridaceae</td>
</tr>
<tr>
<td>Cadmium</td>
<td>100</td>
<td>2</td>
<td>Brassicaceae, Asteraceae, Chenopodiaceae</td>
</tr>
<tr>
<td>Cobalt</td>
<td>1000</td>
<td>30</td>
<td>Lamiaceae, Scrophulariaceae</td>
</tr>
<tr>
<td>Copper</td>
<td>1000</td>
<td>34</td>
<td>Cyperaceae, Lamiaceae, Brassicaceae, Poacea, Scrophulariaceae</td>
</tr>
<tr>
<td>Gold^a</td>
<td>1</td>
<td>–</td>
<td>Brassicaceae</td>
</tr>
<tr>
<td>Lead^a</td>
<td>1000</td>
<td>14</td>
<td>Compositae, Brassicaceae</td>
</tr>
<tr>
<td>Manganese</td>
<td>10,000</td>
<td>11</td>
<td>Apocynaceae, Convolvulaceae, Proteaceae</td>
</tr>
<tr>
<td>Nickel</td>
<td>1000</td>
<td>320</td>
<td>Brassicaceae, Convolvulaceae, Flacourtiaceae, Violaceae, Euphorbiaceae</td>
</tr>
<tr>
<td>Selenium</td>
<td>100</td>
<td>20</td>
<td>Fabaceae, Brassicaceae</td>
</tr>
<tr>
<td>Silver^a</td>
<td>1</td>
<td>–</td>
<td>Brassicaceae</td>
</tr>
<tr>
<td>Thallium</td>
<td>100</td>
<td>1</td>
<td>Brassicaceae</td>
</tr>
<tr>
<td>Uranium^a</td>
<td>1000</td>
<td>–</td>
<td>Brassicaceae</td>
</tr>
<tr>
<td>Zinc</td>
<td>10,000</td>
<td>16</td>
<td>Brassicaceae, Crassulaceae, Leguminosae</td>
</tr>
</tbody>
</table>

^a For induced hyperaccumulation.

Source: (Sheoran, Sheoran, & Poonia, 2009)
### Table 3 Metal Concentration and Biomass Production

Some specific plant hyperaccumulators with their metal concentration and definite biomass (kg/ha).

<table>
<thead>
<tr>
<th>Elements</th>
<th>Plant species</th>
<th>Concentration mg/kg dry matter</th>
<th>Biomass kg/ha</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Cadmium</td>
<td><em>Thlaspi caerulescens</em></td>
<td>3000 (1)</td>
<td>4000</td>
<td>Reeves et al. (1995, 2001), Brooks (1997)</td>
</tr>
</tbody>
</table>
| 2 Cobalt | *Haumaniastrum robertii*  
*Berkeleya coddii* | 10,200 (1) | 4000 | Brooks (1977), Brooks (1997)  
Robinson et al. (1999), Keeling et al. (2003) |
| 3 Copper | *Haumaniastrum*  
*Katangense*  
*Ipomea alpina* | 8356 (1) | 5000 | Brooks (1977), Brooks (1997)  
Baker and Walker (1990) |
| 4 Gold (induced-hyper-accumulation) | *Brassica juncea, Berkeleya coddii*  
*Chicory*  
*C. linearis* | 10 (0.001) | 20,000 | Anderson et al. (1999a,b)  
Lamb et al. (2001)  
Msuya et al. (2000)  
Gardea-Torresdey et al. (2005) |
| 5 Lead | *Thlaspi rotundifolium* | 8200 (5) | 4000 | Reeves and Brooks (1983) |
| 6 Manganese | *Macadamia neurophylla* | 55,000 (400) | 30,000 | Jaffre (1980), Brooks (1997) |
| 7 Nickel | *Alyssum bertoloni*  
*Berkeleya coddii*  
*Streptanthus polygaloides* | 13,400 (2)  
17,000 (2) | 9000  
18,000 | Minguzzi and Vergnano (1948)  
Morrey et al. (1992)  
Brooks (1997)  
| 8 Silver | *B. juncea*  
*Medicago sativa* | – | – | Harris and Bali (2008) |
| 9 Thallium | *Iberis intermedia*  
*Biscutella laevigata* | 4055 (1) | 8000 | Brooks (1997), Leblanc et al. (1999)  
Anderson et al. (1999b) |
| 10 Uranium | *Atriplex confertifolia* | 100 (0.5) | 10,000 | Cannon (1964) |
| 11 Zinc | *Thlaspi calaminare* | 10,000 (100) | 4000 | Baumann (1885), Brooks (1997) |

NB: values in parentheses are mean concentrations usually found in non-accumulator plants.

Source: (Sheoran, Sheoran, & Poonia, 2009)
4.1 Phytomining Process

**Figure 4 Integrated Process of Gold Phytomining**

Source: (Sheoran, Sheoran, & Poonia, 2009)

**Figure 5 Process of Phytomining**

Source: (Anderson et al., 1999)
4.2 Gold Phytomining Lifting Mechanism

1. Metal Solubilisation

Gold is immobile and insoluble in soil. However, it can be mobilised by cyanogenic plants and microbial activity. (Sheoran et al., 2013)

2. Uptaking into The Roots

Gold is soft acid in its cation form. It could bind with soft base like S and N. It can be absorb by root plant.

3. Transporting

Transported using xylem. After bio activation, root exudates, micro-organism exudates and cyanogenic.

4. Detoxification and Sequestration

Distribution (Trichome, epidermis, mesophyll, cell wall and vacuoles)
Detoxification (Chemical conversion, complexation with amino acid)
Sequestration (Vacuoles)

**Figure 6 Lifting Mechanism**
### 4.3 Chemical use in Phytomining

**Table 4 Chemical Use in Phytomining**

<table>
<thead>
<tr>
<th>Chemical name</th>
<th>Formula</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium thiocyanate</td>
<td>NH$_4$SCN</td>
<td>Anderson et al., 1998; Gardea-Torresdey et al., 2005; Msuya et al., 2000; Rodríguez-Lopez et al., 2009; Rodríguez et al., 2006</td>
</tr>
<tr>
<td>Ammonium thiosulphate</td>
<td>(NH$_4$)$_2$S$_2$O$_3$</td>
<td>Anderson et al., 1998; Lamb et al., 2001; Msuya et al., 2000; Rodríguez-Lopez et al., 2009</td>
</tr>
<tr>
<td>Thiourea</td>
<td>CH$_4$N$_2$S</td>
<td>de la Rosa et al., 2009; Gardea-Torresdey et al., 1999; Rodríguez-Lopez et al., 2009; Rodríguez et al., 2006</td>
</tr>
<tr>
<td>Sodium thiocyanate</td>
<td>NaSCN</td>
<td>Lamb et al., 2001</td>
</tr>
<tr>
<td>Potassium iodide</td>
<td>KI</td>
<td>Lamb et al., 2001</td>
</tr>
<tr>
<td>Potassium cyanide</td>
<td>KCN</td>
<td>Lamb et al., 2001</td>
</tr>
<tr>
<td>Potassium bromide</td>
<td>KBr</td>
<td>Lamb et al., 2001</td>
</tr>
<tr>
<td>Sodium cyanide</td>
<td>NaCN</td>
<td>Anderson et al., 1998; Piccinin et al., 2007; Rodríguez-Lopez et al., 2009; Wilson-Corral et al., 2011</td>
</tr>
</tbody>
</table>

Source: (Wilson-Corral, Anderson, & Rodríguez-Lopez, 2012)
4.4 Phytomining Scenario

**Figure 6: Phytomining Application in Tailing Dump**

Source: (Hunt et al., 2014)
4.5 The Economics of Phytomining

Figure 7 Economics Factors of Phytomining

Source: (Cited from Brooks et al., 1998 and Harris et al., 2009 in Sheoran et al., 2013)
4.6 The Economics of Phytomining (Continued)

Using a crop of B. juncea and chelating agent NaCN.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Price of metal ($/t)</th>
<th>Metal content (mg/kg) in biomass yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>39,223,902</td>
<td>1 10 15 20 30</td>
</tr>
</tbody>
</table>

Sources: Gold prices provided by KITCO Bullion dealers (http://www.kitco.com).

**Figure 8** Profitability versus soil gold concentration

Source: (Sheoran et al., 2013)
5. PHYTOMINING IN THE FUTURE

5.1 Phytomining Limitations

- Climate and Seasonal Dependence
- Geochemical Factors
- Chemical Accumulation in soil

LIMITATIONS
5.2 Phytomining Improvements

*Figure 9 Improvement Strategy of Hyperaccumulators*

Source: (Sheoran et al., 2009)
Phytomining is economically and technically reliable to be used in low concentration gold metal.

Phytomining could reduce significantly environmental damage that might cause by surface mining method.

This method can include some related disciplines to research suitable plants for application.

In line with gold extraction, it can also generate another source of energy, for example biomass.

Phytomining will be accepted by most people.

It has almost sustainable mining parameters and compatible with the demand of green economic campaign

It is suggested to study plant genetics to improve plants extraction performance.
7. REFERENCES


THANK YOU