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Gold Phytomining: A New Idea for Environmental Sustainability in Indonesia

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Abstract - New technology is needed to protect the safety and health of communities and the environment at ASGM locations in Indonesia. This technology must be simple, cheap, easy to operate, and financially rewarding. A proven option that should be promoted is phytoextraction, a farming activity that could develop agriculture as an alternative livelihood in ASGM areas. This is a technology where plants are used to extract metals from waste rock, soil, or water. These metals can be recovered from the plant in its pure form, then be sold or recycled. Gold phytoextraction is a commercially available technology, while an international research has shown that phytoextraction will also work for mercury. In the context of this idea, tailings would be contained in 'farming areas' and cropped using phytoextraction technology. Gold and mercury would be extracted in the crops, with the remaining mercury burden of the tailings becoming adsorbed to soil constituents. The system would be financially rewarding to 'gold farmers'. The economic value of this scenario could facilitate the clean-up and management of mercury pollution, reducing the movement of mercury from tailings into soil, water, and plants, thereby mitigating environmental and human risk in the mining areas. The goal of the described research is to promote agriculture as an alternative livelihood in ASGM areas. The gold value of the phytoremediation crop should provide a cash incentive to artisanal farmers who develop this new agricultural enterprise. The benefits will be social, environmental, and economic, as opportunities for education, employment, new business, the containment of toxic mercury, food safety and security, and revenue are all realized.

Keywords: gold, phytomining, tailing, new business, phytoremediation, agriculture

Introduction

Gold is a precious metal on earth that millions of people depend their life on this metal. Despite of the prosperity target, beneath it many issues are related to gold mining, such as an environmental issue. However, science is always developing to cope with the issues, in order to minimize the environmental impact and targeting people prosperity.

Modern gold mining operations conducted in Indonesia by multinational mining companies, like in most countries, are regulated and efficient. Mined ore is leached with cyanide through a Carbon In Pulp (CIP), Carbon In Leach (CIL), or heap leach circuit to extract gold from the rock in the majority of these operations. Plans are generally in place to contain contaminated waste, and to rehabilitate the mining area once an operation finishes.

Past mining operations, however, environmental risk in the form of chemicals, heavy metals, and sediment discharged from waste areas and interact with ecosystems is present. Runoff and leakage from tailings and waste rock can pollute streams flowing out of the mining area, causing widespread damage downstream. This has a direct affect on communities and people who depend directly on goods and services provided by ecosystems, and the quality of, and their access to, natural resources. An increase in wealth generated by commodities can be offseted by a decrease in wealth attributed to natural capital destroyed through the commodity production cycle (specifically the average person's ecosystem). The result is a population that is poorer, despite an apparent increase in gross domestic product. Any rise in GDP in this context is at the expense of an average person's natural asset.

Contamination at a historic mining site is not necessarily bad. It is the scenario of this contamination interacting with soil, plants, animals, and people that must be mitigated or managed. Professional assessment is therefore essential to diagnose environmental risk, and to define a remediation plan. Some of the worst mining pollution around the world that is seen today, is due to historic operations where no environmental risk assessment or rehabilitation procedures were put in place upon the conclusion of mining operations.

The category of mining that causes the greatest level of environment damage in Indonesia is 'artisanal mining'. This term describes an informal and unregulated system of small-scale mining prevalent in many of the world's poorest countries and communities. Artisanal miners do not make large profits; they strive to make sufficient money to support their immediate family. Many metals and minerals are mined using artisanal methods, but high value commodities such as precious metals and gemstones provide the greatest return. In the context of gold mining, the term artisanal and small-scale gold mining (ASGM) is used to describe this practice.

What Is Phytomining?

Phytomining is the production of a 'crop' of a metal by growing high-biomass plants that accumulate high metal concentrations (Brooks *et al*., 1998). A phytomining operation would therefore entail planting a crop over a low-grade ore body or mineralized soil, implementing appropriate land management techniques to ensure metal uptake, and then harvesting and incinerating the biomass to produce a commercial 'bio-ore' (Brooks *et al*., 1998).

Phytomining offers several advantages over conventional mining (Brooks *et al*., 1998), which include (a) the possibility of exploiting ore bodies or mineralized soils otherwise uneconomic to develop, (b) its environmental impact is minimal when compared with the erosion caused by open-cut mining, (c) the operation would be visibly indistinguishable from a commercial farming operation, (d) a 'bio-ore' has a higher metal content than a conventional ore and thus needs less space for storage, and (e) because of its low sulphur content, smelting a 'bio-ore' does not contribute significantly to acid rain.

Phytomining is actually a subset of a larger field of research known as phytoextraction, the process of using plants to beneficially absorb mineral species from soils, sediments, and groundwater. It involves the cultivation of tolerant plans that concentrate soil contaminants in their above-ground tissues. At the end of the growth period, plant biomass is harvested, dried or incinerated, and the contaminant-enriched material is deposited in a special dump or added into a smelter. The distinction between phytoextraction and phytomining is that in phytomining, the metal accumulated by plants is sufficiently valuable to economically justify the recovery of this metal in pure form. To date, phytomining has been trialled, to varying degrees of success, for nickel and gold.

The more common application of phytoextraction is phytoremediation, where non-naturally occurring contaminants are recovered for disposal or reuse. Phytostabilisation is used to describe a land-management technique where contaminant species are immobilized *in situ* via plant action. In contrast to phytoremediation, the objective in phytomining is to recover a mineral (metallic) commodity for commercial gain. Consequently, phytomining almost always refers to the recovery of heavy metals.

Phytoremediation and phytomining are being developed as commercially viable environmental technologies by many groups around the world. Massey University has an international reputation for conducting novel and important phytoremediation research at historic and active mine sites in New Zealand, Australia, Fiji, China, USA, Mexico, Brazil, and South Africa. Massey University scientists have many years of experience in the design and application of phytoremediation projects. A New Zealand company that has a research relationship with Massey University has proprietary expertise in the processing of plant biomass to recover metals, including gold. Research in New Zealand has investigated a system where gold and mercury are recovered by the same crop of plants from soil or tailings at an ASGM location elevated in both of these metals (Moreno *et al*., 2005).

How Does Phytomining Work?

Phytomining works through phytoextraction, thus hyperaccumulator plants. Many extensively studies on hyperaccumulators have been done by researchers including using *Thlaspi sp.* to hyperaccumulate Cd, Ni, Pb, and Zn. For example, *Thalspi caerulescens* could remove as high as 60 kg Zn/ha and 8.4 kg Cd/ha (Robinson *et al*., 1998), due to specific rooting strategy and a high uptake rate resulting from the existence in this population of Cd-specific transport channels or carriers in the root membrane (Schwartz *et al*., 2003).

Hyperaccumulators efficiently extract metals from the metalliferous soils and then translocate metals to above ground tissues. After sufficient growth, plant is harvested and left for drying. Dried plant material is reduced to an ash with or without energy recovery, which is further treated by roasting, sintering, or smelting methods, which allow the metals in an ash or ore to be recovered according to conventional metal refining methods such as acid dissolution and electrowinning (Figure 1) (Robinson *et al*., 1999).

Plants have shown several response patterns to the presence of high metal concentration in the soils. Most are sensitive to high metal concentrations and others have developed resistance, tolerance, and accumulate them in roots and above ground tissues, such as shoot, flower, stem, and leaves. The current definition of a hyperaccumulator is a plant that is able to accumulate metal to a concentration that is 100 times greater than "normal" plants growing in the same environment. Sheoran *et al.* (2009) stated that metal hyperaccumulation was a complex and rare phenomenon that occurs in plant species with high metal uptake capacity. The mechanism of metal hyperaccumulation involves several steps (Figure 2), which are:

1. solubilization of metal from the soil matrix,
2. root absorption and transport to shoot, and
3. distribution, detoxification, and sequestrian of metal ion.

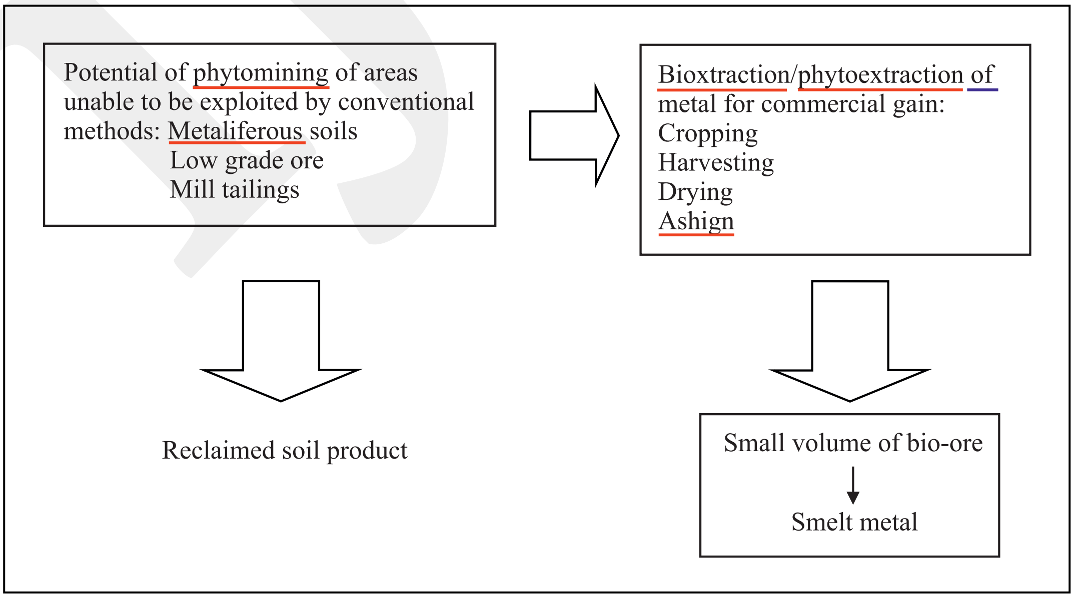

Figure 1. Integrated process for bioharvesting of metals by phytomining.

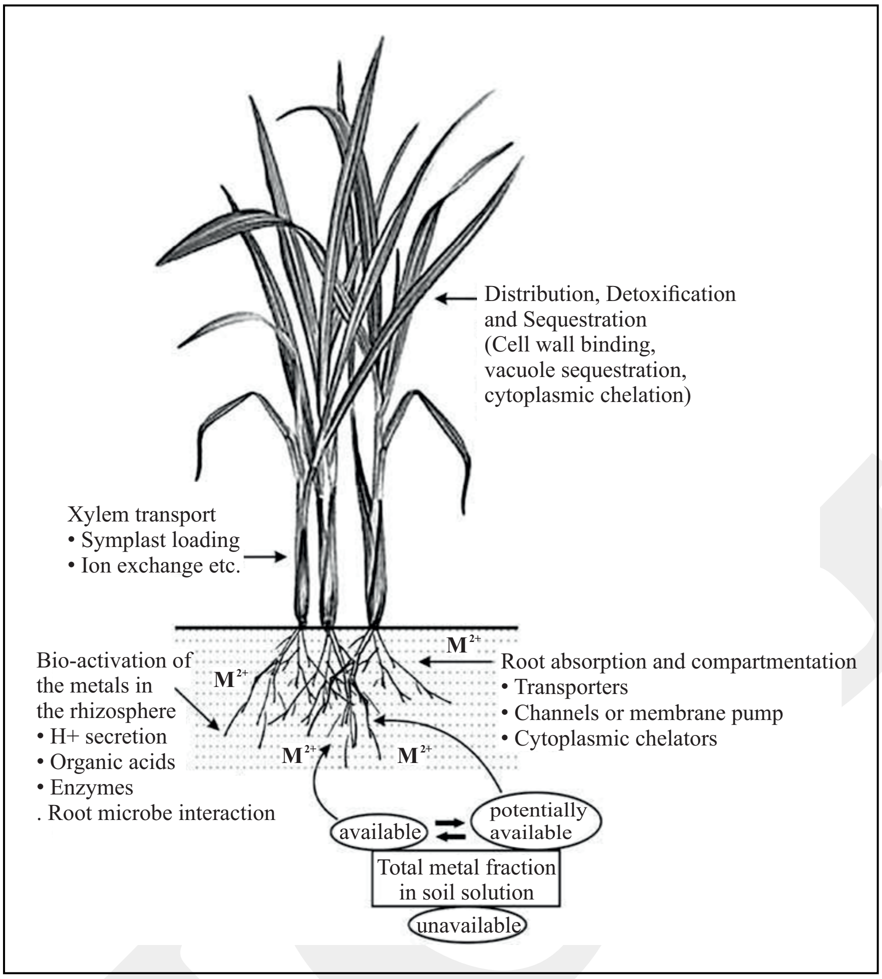

Figure 2. General mechanism of metal hyperaccumulation by plants.

Method Gold Hytomining

Theory and Practice

A review of pyhtomining (Sheoran *et al.*, 2009) has stated that gold has been suggested as a potential candidate for phytomining. Tailing areas usually contains residual gold in very low concentrations, whereas the relatively high concentrations found in heap leach pads and waste dumps. Plants normally do not accumulate gold; the metal must be made soluble before uptake can occur. The residual gold could be extracted using induced hyperaccumulation if the substrates were amenable to plant growth. The concentration of gold that can be induced into a plant is dependant upon the gold concentration in the soil on which the plant is growing.

Anderson *et al.* (2005) has showed that approximately 2 mg of gold per kg of soil is needed by considering a soil profile of 20 cm depth to achieve 100 mg/kg of plant dry mass. Many researches have shown that uptake of gold can be induced using lixiviants such as sodium cyanide, thiocyanate, thiosulphates. In an induced hyperaccumulation operation of gold, the geochemistry of the substrate (pH, Eh, and chemical form of gold) will play a rule of the solubilizing agent necessary to affect the uptake of the precious metal. For low-pH sulfide tailings, gold is made soluble by thiocyanate, and for high-pH unoxidised sulfide tailings gold is soluble with thiosulphate (Anderson *et al.*, 1999).

Result and Discussions

In the last decade, there have been many reports of gold accumulation by plants, in particular trees. Work conducted over 30 years in Canada showed that common conifers could accumulate up to 0.02 mg/kg gold over gold mineralization. In addition, Dunn (1995) reported a background level of gold in plants of 0.0002 mg/kg dry weight, although this author stated that values up to 0.1 mg/kg could be found.

Hyperaccumulation of gold was defined in 1998 as accumulation greater than 1 mg/kg, this limit being based upon a normal gold concentration in plants of only 0.01 mg/kg (Anderson *et al.*, 1998a,b). Anderson *et al.* (1998b) induced Indian mustard (*B. juncea*) with ammonium thiocyanate at the rate of 0, 80, 160, 320, and 640 mg/kg dry substrate weight in pots containing an artificial 5 mg/kg finely disseminated gold rich material, analogous to a natural, oxidized, nonsulfidic ores. Hyper-accumulation of Au was achieved above a thiocyanate treatment level of 160 mg/kg and yielded up to 57 mg/kg Au.

A similar experiment with *B. juncea* grown in a medium containing 5 mg/kg Au prepared from finely powdered native Au (44 lm) and treated with ammonium thiocyanate at an application rate of 250 mg/kg also supported the results (Anderson *et al.*, 1999b). Anderson *et al.* (2005) also estimated that a harvested crop of 10,000 kg/ha biomass (dry) with gold concentration of 100 mg/kg, which would yield 1 kg of gold/hectare could be economically viable. They experimented with *B. juncea* (Indian mustard) and *Z. mays* (corn) induced with sodium cyanide and thiocyanate grown on oxidized ore pile containing 0.6 mg/kg gold. They reported that *B. juncea* showed the best ability to concentrate gold giving an average of 39 mg/kg after sodium cyanide treatment. The highest individual gold concentration determined through an analysis of selected biomass was 63 g/kg (NaCN treatment of *B. juncea*) (Anderson *et al.*, 2005).

Gold phytomining has also been reported by Msuya *et al.* (2000) with five root crops (carrot, red beet, onion, and two cultivars of radish) grown in artificial substrate consisting of 3.8 mg/kg gold, and concluded that carrot roots yielded 0.779 Au kg/ha, worth US$ 840; by adding chelaters ammonium thiocyanate and thiosulphate carrot roots yielded 1.45 Au kg/ha of final worth US$ 7,550. Lamb *et al.* (2001) induced plant species *B. juncea, B. coddii*, and Chicory with thiocyanate and cyanide solutions to determine gold concentration in different parts of plants. The ashed plant material was dissolved in 2 M HCl, followed by solvent extraction of the gold into solvent methyl isobutyl ketone (MIBK). Addition of the reducing agent sodium borohydride to the organic layer caused a formation of black precipitate at the boundary between the two layers and heating this precipitate to 800°C caused formation of metallic gold. Gold concentrations ranged from negligible in the leaves of *B. coddii* induced with thiocyanate, to 326 mg/kg Au dried biomass in the leaves of *B. juncea* induced with cyanide. The chemical additives KI, KBr, $N_aS_2O_3$, and NaSCN were also used with the *B. juncea* and Chicory.

The results showed varying degrees of hyperaccumulation with all chemical treatments. Cyanide again gave the best results with 164 mg/kg Au dried biomass measured in the Chicory plant. NaS_2O_3, KI, and NaSCN gave maximum results of 51, 41, and 31 mg/kg Au dried biomass, respectively. Gardea-Torresdey *et al.* (2005) have reported that *C. linearis* (desert willow - a common inhabitant of Mexican Chihuahuan Desert) is a potential plant for gold phytomining. Desert willow seedlings grew very well in the presence of NH4SCN concentration lower than $1x10^{-4}$ mol/ L. It has been reported that shoot elongation was also not affected by either the Au or NH4SCN concentrations. In addition when using NH4SCN at a concentration of 10^{-4} mol/L with 5 mg Au/L, Au uptake was enhanced by approximately 595, 396, and 467 percentages in roots, stems, and leaves, respectively, compared with gold uptake by plants grown in only 5 mg Au/L. Their studies also showed that this plant produced Au (0) nanoparticles with an approximate radius of 0.55 nm. Mohan (2005) recommended phytomining to be a novel cost-effective technology to extract gold from larger residual dumps (mounds of tailings) and from low-grade ores at KGF (Kolar Gold Fields) in Karnataka. Continuous conventional mining has depleted the level of gold up to 3 mg/kg, hence union government closed the mine. Committees worked over closed mine, proposed a scheme to recover gold from larger residual dumps (mounds of tailings) that had accumulated over the years. Studies have shown that there are about 33 million tonnes of dumps accumulated over the years with a concentration of gold 0.7 - 0.8 mg/kg, which may be a source of 24,000 kg of gold.

Economic Viability of Gold Phytomining

The general target for a gold phytomining operation is to yield 0.5 kg of gold from ever hectare (unit area) of operation. This gold yield is possible through harvesting 5 t/ha of dry biomass containing an average gold concentration of 100 mg/kg (this unit is the same as g/t). At a gold price of US$ 1,500 an ounce, 0.5 kg of gold is worth US$ 24,113. The modelled costs to grow, tend, treat, and process 5 tonnes of plant material are approximately US$15,000. This generates a gross profit of just over US$ 9,000 per hectare. Increased biomass per hectare will lead to an increased yield of gold and increased gross profit. An average gold concentration in the biomass above or below 100 mg/kg will also change the expected gross profit.

The limiting factor for the gold concentration in plants is the total gold concentration in the soil (tailings or waste rock), and the fraction of this total gold that can be made available for plant uptake. There must be a gold concentration in the soil of 0.5 g/t or greater for a pre-feasibility study to be warranted. The cash value of the crop is not the only positive economic parameter. The gold phytomining process will also remove certain contaminants from the soil (*e.g.* copper, arsenic, mercury) or will degrade contaminants within the plant root zone (cyanide). Several years of successive ‘gold cropping’ will reduce contaminant levels, reducing environmental risk and remediating the site. The gold value of the gold crop will subsidize or outright pay for complete site remediation.

The Projects

An early research of gold phytomining in Sekotong of West Lombok District was conducted in 2011. A plot of four different species which were cassava, corn (*Zea mays*), *Brassica juncea,* and Sunflower directly planted on cyanidation tailing (Figure 3). The Au concentration on the cyanidation tailings was in the range of 0.58 - 6.58 ppm. The source of material used in cyanidation process is from amalgamation tailings, and the Au concentration of amalgamation tailings is between 1.75 - 14.71 ppm.

Figure 3. Four spesies growth at cyanidation tailings from ASGM Sekotong, West Lombok, Indonesia.

After three months of growing, it showed that corn and cassava survived in the extreme growth medium. A week before harvesting, the plants was treated by CN and fresh/dry biomass collected for further laboratory analysis. The samples were analyzed in an analytical laboratory of Mataram University, and the results are showed in Table 1. The results indicate that there was a high prospect of using these local plants for gold phytomining.

Table 1. Au Concentration on Plant Samples

Time of harvesting	Sample type	Au (ppm)
1	Dry corn leaves	3.40
1	Dry *brassica*	1.94
1	Dry cassava leaves	1.96
2	Fresh cassava leaves	2.17
2	Dry cassava leaves	1.49
3	Fresh cassava leaves	1.80
3	Fresh cassava leaves	1.41

Anderson’s current study has showed that gold phytomining is being actively developed in Mexico, a country with a long history of gold mining and a legacy of contaminated mining sites. Many historic mining locations have tailings with a gold grade in excess of 1 g/t. Gold phytomining field trials have been conducted in Mexico for a number of years. These trials have involved collaboration between the Universidad Autonoma de Sinaloa (Mexico) and the New Zealand biomass processing company, Tiaki International Ltd. (with Anderson).

In early 2012 a trial was conducted at a mine site with surface tailings of approximately 3 ha at an average gold grade in excess of 1 g/t. Sunflowers were grown on this mine waste and treated to induce gold uptake. The average gold concentration in the plant material at harvest was greater than 20 g/t with the maximum gold concentration in excess of 30 g/t. This biomass is currently being processed. However, taking the international market value of gold in 2012 into account, the observed gold concentration in the plants is considered to be economic. This average gold concentration was not considered to be optimal. Future trials will seek to considerably increase the gold concentration accumulated by the field- harvested plants.

Conclusion

Gold phyotmining is a promising technology to be used on gold tailings in Indonesia. The success and sustainability of gold phytomining will require a balance between the economic incentives to recover this precious metal and environmental sustainability in the field.

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