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Phytomining of gold: A review

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ABSTRACT

Phytomining of gold involves extracting gold from soil substrates by harvesting specially selected hyperaccumulating plants. Phytomining has potential to allow economic exploitation of low grade ores or mineralized soils that are too poor for conventional mining of metals. Gold is the most promising option for phytomining as its market value is increasing continuously. This paper reviews various aspects of phytomining of gold, mechanism of gold uptake, economic analysis, and methodology of gold recovery from plant biomass. Future scopes of gold phytomining are also discussed.

Contents

1. Introduction

Plants have the remarkable ability to accumulate metals in their tissues from the soil in which they are grown. It has been recognized that some plants are able to hyperaccumulate metals to a concentration much higher than the substrate concentration. To exploit this property, plants capable of growing in high-mineral environments were applied to extract metals from the soil substrate, known as phytoextraction (Chaney et al., 1998; Garbisu and Alkorta, 2001). Phytoextraction has a broad application in two main areas — phytoremediation and phytomining. (i) Phytoremediation, where metal contaminants are stabilized or recovered for secure disposal (McGrath and Zhao, 2003), and (ii) Phytomining, where valuable metals such as gold (Au), platinum (Pt), and thallium (Tl) are recovered via cropping for monetary return (Anderson et al., 1999a,b; Brooks et al., 1998).

Conventional mining is usually performed from the ores that have a high concentration of target metal (above the cut-off grade) and requires huge capital investment. To be economically viable, such operation requires ore bodies with sufficient ore deposits. Mining activities and production of metals have increased many folds due to continuous increase in the world population during the past 20 years. This increase in consumption of metals has led to their depletion in nature. However there are much larger areas of low grade ores, where percentage of

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metal is well below the metal content required to be economically extracted and smelted by conventional techniques. These low grade ores have substantial quantities of precious and other metals that can be efficiently extracted by plants in their harvestable parts. Thus to meet the ever-increasing demand of metals, phytomining technology is the most feasible, economically acceptable, environmentally sound, and supplementary as well as an alternative plant based technology for exploiting and recovering the precious metals from low grade surface ores or mineralized soils (Anderson et al., 1999b, 2003, 2005; Sheoran et al., 2009).

Phytomining involves the use of hyperaccumulating plants to extract valuable metals from the substrate. Hyperaccumulating plants occur naturally for many metals such as nickel, cadmium and manganese etc., where most of the metals are bio-available in soil solution for plant uptake (Baker and Brooks, 1989). This phenomenon of phytoaccumulation may also be induced in some high biomass plant species (e.g. *Brassica juncea*) by addition of chemicals to solubilize metals, such as gold, lead, zinc and uranium and make them available for plant uptake (Anderson et al., 1998a,b; Ebbs et al., 1998).

Gold is widely dispersed throughout the earth crust at a very low level (0.005 mg/kg) therefore it is very important to find naturally occurring concentrations. The scarcity of gold and its value, due to mankind's fascination, have led to gold being one of the most important metals in our daily life. Worldwide, there are large tonnages of gold deposits in natural mineralized soil or in mine waste (mine tailings), and are wasted if not explored. Phytomining not only provides a potential route of extracting precious metals from these areas, also additionally increases levels of soil carbon, nutrients and biological activity, thereby increasing the success rate of subsequent native planting strategies (Brooks and Robinson, 1998; Salt et al., 1995). Phytomining is reported to be less intrusive, requires reduced energy than traditional mining techniques which are energy and resource intensive, and require substantial site remediation at the end-of-life of the mine. Its effect on the environment is minimal because of the stabilizing action of the plants when compared with the erosion caused by opencast mining operation (Robinson et al., 2003). Phytomining could also assist in the sustainable closure of mining sites. Gold can be recovered from the native plants grown during the process of revegetation at the closure sites, thus generating revenue along with rehabilitation (Wilson-Corral et al., 2011).

The process of phytomining uses solar energy to generate bio-ore. “Bio-ores” are virtually sulphur free and their smelting requires less energy than sulphide ores. The metal content of a bio-ore is usually much greater than that of a conventional ore and requires less storage space. Despite the lower density of a bio-ore and its low sulphur content, smelting of a ‘bio-ore’ does not contribute significantly to acid rain (Anderson et al., 1999b; Brooks et al., 1998).

2. Accumulation of gold by plants

The link between mineralization and plants has been recognized since medieval time, but it was not until the 20th century that it became possible to analyze plant tissues for these metal concentrations (Anderson et al., 2003). The years of strong selective pressures exerted by the metal loaded soils on associated plants led to the evolution of communities of plants with biological mechanism to resist, tolerate or thrive that are typically endemic to their native metalliferous soils. Such plant communities that evolved on metal rich soils are called metallophytes. These can survive in the extreme physical and biological conditions such as with toxic metal ions, poor physical structure of soil, nutrient deficiencies and soil acidity (Sheoran et al., 2008; Whiting et al., 2004). Baker and Brooks (1989) classified the metallophytes into three categories: i) indicators; plants which take up metals in proportion to its quantity in soil and are used for exploration of mineralized soil ii) excluders; plants which do not take up metals to their shoots rather accumulates them into roots, and iii) hyperaccumulators; plants which accumulate inordinate concentration of toxic metals in their shoots. Hyperaccumulating plants can accumulate metal to a concentration that is 100 times more than “normal” plants growing in the same environment (Anderson et al., 2003).

Gold and its chemical derivatives has been a subject of interest since ancient times. The uptake of gold by plants has fascinated scientists for over 100 years. Lungwitz (1900) was the first to suggest the analysis of plant tissue for gold to locate the gold deposits. Further research on biogeochemistry of gold and the use of plants as an exploration tool for gold rich deposits was followed in the Soviet Union. Goldschmidt (1935) reported gold and silver in the humus of an oak-beech forest in Germany. Kitayev and Zhukova (1980) suggested that plants show no particular affinity for gold, but absorb it whenever it is present in soil nutrient solution. Erdman and Olson (1985) reported Douglas-fir (*Pseudotsuga menziesii*) and sagebrush or wormwood (*Artemesia californica*) for gold exploration in the Soviet Union. Based on the studies carried out on 33 different plant species Kovalevskii and Kovalevskii (1989) classified plant species and organs into four groups on the basis of concentrations of gold in plant tissues as non barrier bio-objects, semi-non barrier bio-objects, barriers and background barriers from the perspective of biogeochemical exploration. Non barrier bio-objects give quantitative information of gold concentration in the growth medium. Semi-non barrier bio-objects shows high concentration limits of 3–300 times the gold concentration in the growth medium. Barriers represent concentration limits of 3–30, giving only qualitative information of the concentration of gold in the growth medium. Background barriers provide neither quantitative nor qualitative information on gold concentration in the growth medium. Some of the species studied, including trees, fungi, lichens, were dahurian larch (*Larix dahhurica*), scots pine (*Pinus silvestris*), silver birch (*Betula verrucosa*), hinggan fir (*Abies neprolepis*), cup lichen (*Cladonia gracilis*), slippery jack (*Suillus luteus*), and balsam fir (*Larix taiga*) etc. They recommended the inner, middle and outer bark of trees as non-barriers and confirmed them as the main organs which can reflect deeply buried gold deposits. This barrier concept states that every plant and plant organ offers varying degrees of resistance to metal uptake. Thus for prospecting an element, the focus of analysis has to be on the specific plants and their organs. Busche (1989) tested Creosote bush (*Larrea tridentata*), burr bush (*Franseria dumosa*), and sagebrush (*Artemesia californica*) plant species for gold biogeochemical prospecting in the arid environment of the Mojave Desert, Los Angeles, California. It was found that creosote bush leaves can be used for prospecting of gold deposits.

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). Natural hyperaccumulating plants of gold are yet to be reported. Solubility and availability of the metal is one of the key limiting factors for gold phytomining (Piccinin et al., 2007). Plants normally do not accumulate gold in its natural form Au (0) due to low solubility in soil. Hence the gold must be made soluble before plant uptake can occur. Various researchers have shown that uptake of gold can be induced using lixiviates such as sodium cyanide (NaCN), thiocyanate, thiosulphates (Anderson et al., 1999a,b, 2003, 2005; Ebbs et al., 2010; Lamb et al., 2001a,b; Msuya et al., 2000; Piccinin et al., 2007; Wilson-Corral et al., 2011). These compounds chelate Au (0) and convert it into Au (I) or Au (III), which are easily bioavailable but in more toxic form of Au (Merchant, 1998). The process of induced gold hyperaccumulation depends upon the gold concentration in the soil. For one treatment, plant will accumulate approximately 20% of the total amount of gold present in the soil (Anderson et al., 2003). Phytomining will target gold only within the root zone of the plants. Anderson et al. (2003) limited the target source of gold phytomining to the top 20 cm of the soil profile.