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Phytomining: A review

V. Sheoran [a], A.S. Sheoran [b,*], P. Poonia [a]

[a] Department of Zoology, Faculty of Science, Jai Narain Vyas University, Jodhpur, Rajasthan 342 011, India
[b] Department of Mining Engineering, Faculty of Engineering, Jai Narain Vyas University, Jodhpur, Rajasthan 342 011, India

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ABSTRACT

Bioharvesting of metals from high biomass crops grown in soil substrates particularly those associated with sub-economic mineralization is termed phytomining. It is a recent more advanced technology of phytoremediation to produce low volume, sulphide-free 'bio-ore', which can either be safely disposed of or, if the target metal is of sufficient economic value, smelted, and recovered. This technology has potential application in the mineral industry to return an economic profit by commercial production of metals via cropping. Numerous sites across the globe are enriched with metals that could potentially be phytomined. In recent years major scientific progress has been made in understanding the potential for application of this herbage-based technique in the mining industry to develop a good relationship between the industry and community. This paper reviews various aspects of phytomining along with the advantages, limitations, and future feasibility of the technology.

Contents

* Corresponding author. Tel.: +91 291 2611512.
E-mail addresses: as_sheoran@yahoo.com, sheoran@sancharnet.in (A.S. Sheoran).

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1. Introduction

Commercial mining of metals is usually performed from ores that have a high concentration of target metals (above the cut-off grade) and requires huge capital investment. Ore bodies of this nature occur only in small localized areas and are being exhausted due to expanding economics, burgeoning populations and disarrayed industrialization. Sub- or low-grade ore occupies much larger area and percentage of metal is well below the metal content required to be economically extracted and smelted by conventional techniques.

Most of sub- or low-grade ore bodies are associated with ultramafic deposits. Ultramafic deposits are formed from magma rich in olivine and pyroxene minerals. Weathering of ultramafic rocks has produced the ultramafic or serpentine soils, characterized by a pH of 6–8, low ratio of Ca/Mg in the exchangeable cations and soil solution, low level of organic matter, nitrogen, phosphorous, potassium, and contains relatively large amounts of nickel, chromium, manganese, cobalt, titanium, iron, magnesium, and other metals (Li et al., 2003b; Berazain et al., 2007a; Chaney et al., 2008). These deposits are scattered throughout the world and usually support a characteristic flora called endemic flora (Brooks, 1987; Robinson et al., 1999). These floras on their native metalliferous soils have constitutive (present in most phenotypes) and adaptive (present only in tolerant phenotypes) mechanism for accumulation or tolerating high metal concentration (Khan et al., 2000). There is a greater need to exploit such areas in the future to generate revenue by extracting saleable metals.

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 (Memon et al., 2001). A focal point of soil plant interactions is the micro ecosystem surrounding the plant roots, the rhizosphere, characterized by different physical, chemical, and biological conditions created by the plant roots and its surrounding soil environment. It is well documented that soil solution is drawn from the roots to the above ground portions of their biomass by plant water uptake, which depends upon the root absorption factor, a dimensionless parameter describing the xylem/soil solution metal concentration quotient (Marschner, 1995; Robinson et al., 2003). Increased understanding of the role of metal extracting plants in circulation of minerals in biosphere has made them important biotechnological tools in mining process from low-grade ores.

Plants have shown several response patterns to the presence of high metal concentrations in the soils. Most are sensitive to high metal concentration and others have developed resistance, tolerance, and accumulate them in roots and above ground tissues such as shoot, flower, stem, and leaves (Barcelo et al., 1994). The phenomenon of plants accumulating inordinate concentrations of heavy metals was termed hyperaccumulation. The current criterion to define a hyperaccumulator is, a plant that can accumulate metal to a concentration that is 100 times greater than "normal" plants growing in the same environment (Brooks et al., 1977; Baker and Brooks, 1989; Anderson et al., 2003).

Hyperaccumulators efficiently extract metals from the metalliferous soils and then translocate them 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 (Fig. 1) (Robinson et al., 1999). Thus phytomining is the in situ removal of metals from sub-economic ore bodies or from contaminated mine sites with the additional aim of recovery of economic amount of metals from the plants (Chaney et al., 1998; Anderson et al., 1999a).

2. Factors influencing the phytomining

A successful phytomining process depends on adequate biomass yield and high metal contents in the harvestable parts of the plants. Many metals are largely immobile and their bioavailability to plant root is restricted. The bioavailability of metals for plant uptake and biomass can be increased by bringing modulation in both internal (plant associated) and external (soil associated) factors.

2.1. Plant associated factors

2.1.1. Hyperaccumulating plants

The term hyperaccumulator was first applied by Jaffre and his co-workers when they observed the accumulation of nickel in *Sebertia accuminata* (Jaffre et al., 1976), but the present connotation concerning the concentration of more than 1000 mg/kg (0.1%) of metal in plant tissues was introduced by Brooks and his co-workers in the year 1977, when they examined the Ni concentration in *Homalium* and *Hybanthus* from different sites throughout the world. For most elements the threshold concentration is 1000 mg/kg (0.1%) dry mass, except for zinc (10,000 mg/kg), gold (1 mg/kg), and cadmium (100 mg/kg) (Brooks et al., 1977, 1998). Hyperaccumulating plants are taxonomically widespread throughout the plant kingdom. Approximately 400 plant species from at least 45 plant families have been reported to hyperaccumulate metals, most of which are nickel hyperaccumulators occurring in ultramafic areas all over the world (Table 1).

Baumann (1885) was the first to report the small herbaceous biennial *Thlaspi calaminare* and *Viola calaminaria*, found near Aachen, Germany, with a foliar zinc concentration of around 1%

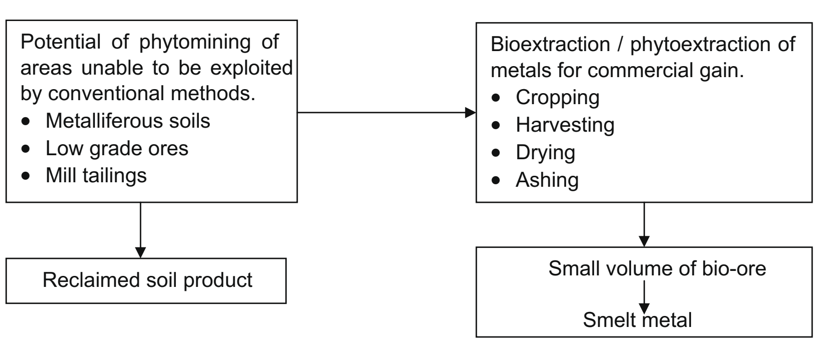

Fig. 1. Integrated process for bioharvesting of metals by phytomining.