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Biomining - recovery of high-tech critical metals

Butu A.[1], Rodino S.[1], Butu M. [1,*]

[1]National Institute of Research and Development for Biological Sciences

*corresponding author: e-mail: marian_butu@yahoo.com

Abstract
Critical metals were defined as those metals essential for high-tech, medical and defense industry but with low availability due to uneven geographical distribution, thus resulting a high price volatility. The challenge of the future is to assure a stable supply of critical materials and implicitly of critical high-tech metals and this will be possible through multiple approaches such as intelligent mining, urban mining, extensive recycling and reutilization. The reports of European Commission regarding critical raw materials will be reviewed. In the same time, potential alternative sources and possible new biotechnologies for the future will be explored. Extraction of metals by means of microorganisms is an established biotechnology and is applied worldwide for processing of sulfidic low-grade ores. The mineral processing using microorganisms has been extended for copper, gold, nickel, cobalt, zinc, and uranium. Here, we shall explore the possibility of biomining for the recovery of critical metals from secondary sources.

Keywords: critical metals, biomining, secondary sources, biotechnology

1. Introduction

A reliable supply of mineral raw materials for European industry is absolutely necessary to secure Europe's prosperity and improve the quality of European citizens' life.

Recent European initiatives have pioneered the development of an EU strategy on raw materials emphasizing the concept of the "added value chain", pursuing the three-pillar strategy to:

(1) ensure the fair and sustainable supply of raw materials from international markets, promoting international cooperation with developed and developing countries;

(2) foster sustainable supply of raw materials from European sources, and (3) reduce consumption of primary raw materials by increasing resource efficiency and promoting recycling.

2. Reports of EU commission regarding critical raw materials

2.1. First report

Between 2011 and 2017 three reports of European Commission regarding critical raw materials were published.

The first report called "Tackling the challenges in commodity markets and on raw materials" provides the list EU-14 with 14 critical raw materials identified at EU level by the Commission, with Member States and stakeholders [EC, 2010].

A transparent, innovative and pragmatic methodological approach to defining "criticality" was developed.

Critical raw materials are those that display a particularly high risk of supply shortage in the next 10 years and are particularly important for the value chain.

The work on identifying critical raw materials also revealed the need for better data and knowledge, and the need to update regularly the list of raw materials to take into account market developments, technological developments (for example, lithium for Li-ion batteries, hafnium for microprocessors, nickel for steel industry), or new information on the environmental impact of a material.

Four countries are the main suppliers of those 14 critical raw materials from the list EU-14.

- China: antimony, fluorspar, gallium, germanium, graphite, indium, magnesium, rare earths - yttrium, scandium, lanthanum and the so-called lanthanides (cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium) and tungsten;
- Russia: platinum group metals - platinum, palladium, iridium, rhodium, ruthenium and osmium;
- The Democratic Republic of Congo: cobalt, tantalum;
- Brazil: niobium and tantalum.

Because other elements which have a low availability at one specific moment may become critical in the near future, the decision to update the list of critical raw materials every three years was taken.

2.2. Second report

In the second report, called "The review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative" six materials were added: borates, chromium, coking coal, magnesite, phosphate rock and silicon metal [EC, 2014].

In addition, greater detail was provided for rare earth elements by splitting them into heavy rare earth elements, light rare earth elements, and scandium. Moreover, tantalum was withdrawn from the list

2.3. Third report

The most recent report was entitled „The 2017 list of Critical Raw Materials for the EU" [EC, 2017].

The new list features 27 raw materials: Antimony, Beryllium, Borates, Cobalt, Coking Coal, Fluorspar, Gallium, Germanium, Indium, Magnesium, Natural Graphite, Niobium, Phosphate Rock, Silicon Metal, Tungsten, Platinum Group Metals, Light Rare Earths and Heavy Rare Earths, Baryte, Bismuth, Hafnium, Helium, Natural Rubber, Phosphorus, Scandium, Tantalum, and Vanadium.

This critical raw material list contains 35 high-tech critical metals. These are metals used in high- and green-technology applications.

These are also classified as 'green minor metals', and are the basis for cleaner technology innovation like energy-efficient batteries and lights, fuel cells and photovoltaic cells (e.g. thin film), catalysts etc.

In other words, these are the metals on which are based the future sustainable technologies, such as renewable energies and energy efficient technologies.

3. Biomining

Biomining is defined as the extraction of minerals from ores by using microorganisms.

The challenges for mining companies are:

- Providing services with no long-term impact on environment;
- Increasing interest in microbial approaches for recovery of critical metals.

Microorganisms are used because they can:

- lower the production costs;
- cause less environmental pollution comparing to the traditional leaching methods;
- very efficiently extract metals when their concentration in the ore is low [Dunbar W, 2017; Ylä-Mella J, 2016].

4. Experimental

A number of fifty samples were collected from mining wastes containing high tech critical metals, from various depths. Samples were collected from mine tailings at a depth of approximately maximum one hundred and twenty-five (125) cm below surface, after which they were placed in clean sterile bags, labeled accordingly and stored at 4 ºC until further analysis.

In order to be used for the microbiological studies, the samples were grounded to obtain a coarse powder.

4.1 Chemicals and media

- Metal(loid)s: Mo, W, Ga, In, Te;
- Cultivation media used for isolation and maintenance of the strains isolated: nutrient agar, nutrient broth, DSMZ 670.

Two different strategies were employed for the isolation of bacteria from the mine wastes samples.

Following the isolation and purification, the strains were evaluated for the ability to grow on minimal agar in the presence of different critical metal concentrations.

The isolated strains were tested for their metal tolerance using the agar diffusion method.

The agar was supplemented with successively higher concentrations (0, 5, 10, 25, 50, and 100 mg /L) of the critical metals mentioned before. The growth of bacteria on the plates containing culture media with no metals was considered as control.

The plates were inoculated with the bacterial isolates and incubated for 2 days.

5. Results

After applying two different strategies for the isolation of bacterial strains, resulted three bacterial strains labelled S1Bn, from S1, and four strains labelled S2Bn from the second protocol performed.

- All of the strains resulted from the samples collected from 50 - 125 cm below the surface of the tailing.
- The strain S2B2 was isolated from the plates incubated at ambient temperature (23 - 24 ° C) and the strain SB3 was isolated from the plates incubated at higher temperatures (above 40 ° C).
- The bacterial colonies were studied with respect to size, color, opacity and form. All bacterial strains proved to be Gram-negative.

6. Conclusion

The bacterial strains isolated are resistant to high concentrations of critical metals and are also capable of recovering critical metals from resources (tailings) with low concentrations in these metals.

The use of these strains in the consortium can lead to the development of a biotechnology for biosolubilization and bioaccumulation of critical metals from tailings, with application *in situ*.

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