Vol.5, No.4, 445-448 (2013)
http://dx.doi.org/10.4236/ns.2013.54057 Natural Science

Farming nickel from non-ore deposits, combined with CO_2 sequestration

R. D. Schuiling

Institute of Geosciences, Utrecht University, Utrecht, The Netherlands; schuiling@geo.uu.nl

Received 4 December 2012; revised 7 January 2013; accepted 19 January 2013

ABSTRACT

A new way is described to recover nickel from common rock-types, by the use of nickel hyperaccumulator plants. The idea of phytomining nickel was suggested earlier, but never implemented. This situation may soon change, because the mining sector suffers from a poor image on account of the impact of mining on the environment, and would like to reduce the pollution and high energy consumption associated with metal extraction. Once phytomining is established as a viable way of nickel production, it is likely that governments will impose nickel mines to realize part of their nickel production by this method. This will lead to a considerable decrease of CO_2 emissions. Phytomining from rocks rich in olivine or serpentine is CO_2-negative. When metal extraction goes hand in hand with CO_2 sequestration, it will improve the image of the mining sector. Other advantages include that unproductive soils can serve to grow nickel hyperaccumulator plants and recover nickel. The extensive mining technology can provide employment to many poor farmers/miners. Countries that want to be self-sufficient in strategic materials, and avoid spending foreign currency on importing them can switch to phytomining. This paper treats different aspects of future nickel farming.

Keywords: Phytomining; Nickel Hyperaccumulators; Weathering; CO_2 Sequestration; Organization of Nickel Farming

1. INTRODUCTION

Nickel is a fairly rare and rather expensive metal. Its main ores are nickel sulfides or nickel laterites. These latter are the tropical soils on top of olivine- or serpentine-rich rocks. Nickel is rather immobile, even under tropical weathering conditions, so it is enriched during the weathering process relative to its source rock, because major components like MgO and SiO_2 are leached out during tropical weathering. Ultramafic rocks (rocks rich in olivine and/or serpentine) have a Ni-content around 0.3%, which is too low to be considered as an ore. Extraction of nickel from its sulfide or lateritic ores is energy-intensive and polluting. It would save a lot of pollution, energy consumption and money if a way could be found to preconcentrate the nickel not from rare nickel deposits, but from common peridotitesin a cheap and environmentally friendly way, before its final recovery as nickel metal.

2. NICKEL HYPERACCUMULATING PLANTS

Many plants can selectively extract specific metal from soils. Nickel hyperaccumulating plants are among the best-known to exhibit this property. Their discovery has led already to speculate on their potential use to phytomine nickel [1,2], but except in some small-scale test studies this idea was never implemented so far. Many nickel hyperaccumulating species are endemic to a particular region, and grow exclusively on soils of olivine- or serpentine-rich rocks with enhanced Ni-concentrations. It may well be that their restriction to this particular rock type has led to their evolution into many different species, each evolving on its own "geochemical island" surrounded by a sea of nickel-poor rocks. A long list of nickel hyperaccumulators can be found in Wikipedia under Hyperaccumulators Table-2: nickel. Close to 400 species have been discovered, mostly in the families *Asteraceae*, *Brassicaceae* and *Euphorbiaceae* [3].

Some genera of nickel hyperaccumulators comprise many species, like the genera *Alyssum* (**Figure 1**) and *Thlaspi*. Many of these species are found in all southern European countries and in Turkey, Syria and Iran, but occasionally in Central Europe, USA, Philippines and

Figure 1. *Alyssum cypriacum*, a nickel hyperaccumulator from Cyprus.

Japan as well. Even on soils that contain no more than 0.3% nickel, the nickel content of their ash may exceed 10% nickel, richer than the richest nickel ores.

3. MINE DUMPS

3.1. A New Role for Mine Dumps-Nickel Farms

Peridotites, in many cases serpentinized, host chromite ores, magnesite ores, asbestos and sometimes PGE mineralisations. This means that there are many hundreds of millions of tons of crushed olivine or serpentine lying on mine dumps on all five continents. By mixing this material with topsoil, spread it, sow an *Alyssum* hyperaccumulator, and add some fertilizer, one could start a nickel farm. All the *Alyssum* hyperaccumulators are perennial plants, so if they are cut at the end of the growing season 10 cm above ground there is no need to sow them again for a period of around 10 years. After a number of years the nickel production will near its end, because the nickel content of that soil is exhausted, so one must add a new layer from the material on the dump and start a new cycle. As all the dump material contains chromite as an accessory mineral, it may be worthwhile to check if the chromite content of the weathered residue has sufficiently increased after the weathering and dissolution of the major minerals to serve as a chromite ore.

The harvest of dry *Alyssum* plants is ashed in an oven, and the nickel metal is extracted from the ash. On his homepage Robinson shows a picture of nickel ingots obtained during phytomining tests. Although the technological process must still be optimized, it is clear that nickel recovery from plant ash with (more than) 10% nickel will be simpler and will require less energy than from sulfidic or lateritic ores with only a few % nickel.

3.2. Another New Role of Mine Dumps-Carbon Sequestration

Wilson *et al.* [4] found that the mine dumps of several former asbestos mines in British Columbia, consisting of ground serpentine, weather extremely fast, 50 times faster than the weathering of basaltic lavas under optimal tropical conditions. Weathering products are a suite of secondary magnesium minerals (a.o. nesquehonite, lansfordite, hydromagnesite) and a magnesium bicarbonate water. This means that the weathering of crushed olivine or serpentine rocks can play an important role in sequestering CO_2. The weathering of basic rocks has been the major process that has kept the CO_2 levels of our atmosphere within reasonable bounds. The Earth has always emitted CO_2, and without a counterbalancing process by which this is removed again and stored in rocks, our atmosphere would be like on Venus. If all the CO_2 stored in limestones, dolomites and organic carbon would be released as CO_2 into the atmosphere, it would have a CO_2 pressure around 100 bar. Thanks to the presence of liquid water on Earth, the carbonic acid emitted by volcanoes can be neutralized by weathering. In countries with sufficient rainfall the typical weathering reaction is:

$$\begin{aligned} &Mg_2SiO_4 + 4CO_2 + 4H_2O \\ &\rightarrow 2Mg^{2+} + 4HCO_3^- + H_4SiO_4 \end{aligned} \tag{1}$$

as corroborated by the analyses of spring waters from olivine rocks [5]. Small amounts of nickel substitute for magnesium in the olivine lattice. After this weathering step, the bicarbonate solutions are transported by rivers to the oceans, where they are deposited as carbonate rocks (limestones and dolomites).

The average nickel content of olivine rocks or their soils that are used for the phytomining of nickel is 0.25% to 0.3%. This means that for every ton of nickel that becomes available by the dissolution of nickel bearing minerals 330 to 400 tons of olivine must dissolve. This sequesters 400 to 500 tons of CO_2 (see above reaction), making nickel farming a very CO_2-negative way of recovering nickel that can make a significant contribution to carbon sequestration.

4. NICKEL FARMING

The nickel farming approach could be implemented as follows. Seeds of hyperaccumulating plants can be sowed on serpentinite or nickel laterite soils, and a modest amount of NPK fertilizer is added. It is assumed that the hyperaccumulating plant species in this case is an *Alyssum*, and some modifications may be necessary when other plant genera enter the picture. After one growing season the *Alyssum* plants are harvested by cutting them at about 10 cm above ground. As nickel accumulating *Alyssum* species are perennial, this will permit the plants to grow again the next season without requiring a new sowing.

If there is a chromite, magnesite or a former asbestos mine nearby, a variation is possible. One can then spread the tailing material over the ground, mixed with some topsoil, and use this as the nickel field. After a number of years the nickel contained in the layer of olivine or serpentine grains becomes exhausted, and one must repeat the operation with fresh material. In this way the tailing dumps are slowly disappearing, thereby clearing the mine sites.

It is even not necessary to have nickel rich rocks at one's disposal at the site of the farming operation. If countries want to make their "unproductive" soils available for CO_2 sequestration and keep the costs low by simultaneous nickel farming, it can be carried out anywhere. One just needs to cover such unproductive fields with a layer of crushed olivine or serpentinite mixed with some topsoil and then treat them as outlined above. Unproductive soils may include the terrains of urban sewage treatment plants, waste incineration sites, the top of waste disposal sites or even roadsides. On sites of urban sewage treatment plants it may be advantageous to mix sewage sludge with crushed olivine as a way to add the required nutrients. Such sites can bring some money while at the same time sequestering CO_2. An advantage of such combinations is that weathering proceeds faster under a vegetation, which, in turn, enhances the uptake of nickel by these same plants. A major role is played by the symbiosis of higher plants with mycorrhizal fungi that secrete a range of organic acids, in which the minerals are quickly dissolved [6,7].

It is possible that some countries that do not dispose of nickel mines themselves favor the possibility of nickel farming on their own territory from poor soils, or soils that are for some reason not available for food production. This helps them to become self-sufficient in nickel and save their foreign currency, while at the same time making a contribution to the battle against climate change and ocean acidification.

5. POSSIBLE ORGANIZATION FORMS FOR NICKEL FARMING

A nickel mine, or in fact any mining company can organize nickel farming by themselves. This makes for a compact organization, as they will have the control over the whole cycle, from the nickel farming to the extraction of nickel metal from the ashes of the plants.

Another well-known model is the so-called outgrower concept. In this model a producer who owns the required nickel extraction technology makes a deal with a number of farmers living around the central site to grow a product that they will sell to the plant owner. Particularly if the fields around are owned by a large number of individuals, this may be the most appropriate model, because the farmers know best how to grow the biggest crops, whereas the producer disposes of the knowledge how to extract nickel in their central technological unit from the crop cultivated by the farmers.

A third alternative would be a corporative of landowners who would together use the required technology, make the best seeds available, and sell their product with a high nickel content (*Alyssum* plants or ashes of *Alyssum* plants) to the highest bidder. If the technology to extract nickel metal from plant ashes is simple, they could even do this last step themselves.

6. A BACK OF AN ENVELOPE BUSINESS CASE

Tests have shown [2] that it is possible to grow close to thousand tons of biomass of *Alyssum* plants per km^2. The biomass of the South African nickel hyperaccumulator *Berkheya coddii* reached even 22 ton/ha [2]. The fairly dry somewhat woody *Alyssum* plants have an ash content around 10%, and the ash contains 10% of nickel. This means that the gross annual value of the product is around 210,000 Euro per km^2 at a nickel price of 21,000 Euro/ton. This is already more than what good soils under similar conditions would bring when planted with wheat, but most of the soils under consideration are not very productive anyhow. This is clear from a look at the soil in **Figure 1**. From this gross value of 210,000 Euro one must deduct the costs of preparing the fields, sowing them and adding fertilizer. On top of this come the costs of harvesting and transport. A slight positive value comes from the caloric value of the dry biomass. Transport costs of the ashed material are negligible, but if the ashing is an essential part of the nickel metallurgy, it is an advantage to have the extraction plant nearby, because in that case the whole harvested biomass must be transported.

7. SOME GENERAL CONSIDERATIONS

When a mining company opens a mine in a rural area, it very often leads to conflicts. Soils become polluted by the mining activity, the cultures of migrant miners and the local sedentary community clash, and this leads often to violent attacks on the mines. It is expected that in a symbiosis of mining and farming, where both sides have an interest in success, such clashes can be avoided.

For many farmers in poor rural areas, the additional income from taking part in nickel farming will be welcome. It will make it possible for them to take thus far unproductive land into cultivation, and the additional cash will permit them to buy some fertilizer, and thus increase their food production.

Once this method of phytomining has been demonstrated, it is likely that countries will require nickel mining companies to produce part of their nickel by nickel farming, as this ecologically favorable method will reduce CO_2 emissions.

The proposal asks for an extensive type of mining, unlike current mining activities that are concentrated in smaller, but richer areas (ore deposits). It is very familiar to farmers, however, who should adopt it without problems.

8. CONCLUSION

Certain metals, like nickel, are effectively extracted from ordinary rocks by special hyperaccumulating plant species. A large number of nickel hyperaccumulating plants are known. By growing these plants on the appropriate soils, nickel can be recovered by farming. This permits a huge preconcentration of the metal without human interference, and at low cost. The nickel containing rocks are common rock-types that share another property, they weather fast. During the weathering process, the minerals react with water and CO_2. This means that nickel farming leads to a considerable sustainable CO_2 capture. Experiments carried out by the Plant Research Institute of the Agricultural University of Wageningen, in which grass was grown on soils with olivine have shown that the olivine reacted fast and that the plant productivity was increased [8].

9. ACKNOWLEDGMENTS

First of all, I want to thank the numerous people who have enthusiastically embraced the concept, and are starting to implement it. For their specific help I want to thank in particular Necat Özgür, Nico Wissing and Hein ten Berge. The Board members of the Olivine Foundation are thanked for their trust in my unusual ideas.

REFERENCES

[1] Baker, A.J.M. and Brooks, R.R. (1989) Terrestrial higher plants which hyperaccumulate chemical elements—A review of their distribution, ecology and phytochemistry. *Biorecovery*, **1**, 81-126

[2] Robinson, B.H., Chiarucci, A., Brooks, R.R., Petit, D., Kirkman, J.H., Gregg, P.E.H. and De Dominicis, V. (1997) The nickel hyperaccumulator plant *Alyssum bertolonii* as a potential agent for phytoremediation and phytomining of nickel. *Journal of Geochemical Exploration*, **59**. 75-86. doi:10.1016/S0375-6742(97)00010-1

[3] Reeves, R.D. and Baker, A.J.M. (2000) Metal accumulating plants. In: Raskin, I. and Finsley, B.D., Eds., *Phytoremediation of Toxic Metals*: *Using Plants to Clean up the Environment*, Wiley, New York, 193-229.

[4] Wilson, S.A., Dipple, G.M., Power, I.M., Thom, J.M., Anderson., R.G., Raudsepp, M., Gabites, J.E. and Southam, G. (2009) Carbon dioxide fixation within mine waste of ultramafic-hosted ore deposits: Examples from the Clinton Creek and Cassiarchrysotile deposits, Canada. *Economic Geology*, **104**, 95-112. doi:10.2113/gsecongeo.104.1.95

[5] Schuiling, R.D. and Praagman, E. (2011) Olivine Hills: Mineral water against climate change. In: Brunn, S., Ed., *Engineering Earth*: *The Impact of Megaengineering Projects*, Springer, Dordrecht, 2201-2206.

[6] Turnau, K. and Mesjas-Przybylowicz, J. (2003) *Arbuscular mycorrhiza* of *Berkheya coddii* and other Ni-hyperaccumulating members. *Mycorrhiza*, **13**, 185-190. doi:10.1007/s00572-002-0213-6

[7] Schuiling, R.D. and Tickell, O. (2010) Enhanced weathering of olivine to capture CO_2. *Journal of Applied Geochemistry*, **12**, 510-519.

[8] Ten Berge, H.F.M., van der Meer, H.G., Steenhuizen, J.W., Goedhart, P.W., Knops, P. and Verhagen, J. (2012) Olivine weathering in soil, and its effects on growth and nutrient uptake in ryegrass (*Loliumperenne* L.): A pot experiment. *PLoS ONE*, **7**, e42098.

