Nickel Phytomining Potential in Serpentine Soil of Sri Lanka: An Implication for Sustainable Mining

The world is experiencing rapid growth of nickel (Ni) demand, especially for lithium-ion batteries used in electric vehicles, while high-grade Ni deposits are being depleted due to expanding economics, growing populations, and disorganized industrialization. Therefore, a major transformation from high-grade low-bulk ores to low-grade high-bulk ores is necessary to secure the future supply chain of Ni [1]. In this context, ultramafic soil is considered a low-grade high-bulk Ni ore, mostly found in tropical countries. However, conventional mining practices are high energy-consuming and generate a tremendous amount of waste, making it impracticable to recover Ni from ultramafic soil. Therefore, phytomining (or farming for metals) is identified as a viable and innovative method for Ni recovery from low-grade high-bulk sources such as ultramafic soil [2].

Some plants can accumulate exceptionally high concentrations of metals (more than 1,000 mg/kg) in their shoot biomass without showing any toxic symptoms. These plant species are collectively known as hyperaccumulators. In the Ni phytomining process, Ni hyperaccumulators are cultivated, harvested, and incinerated to produce the metal-enriched ash (or bio-ore), from which the metal is recovered (Figure 1) [3]. More than 500 Ni hyperaccumulators have been identified in Ni-bearing environments [4]. Field trials in low-grade high-bulk Ni-enriched soils worldwide have shown the effectiveness of phytomining using various Ni hyperaccumulator plants. Among them, phytomining experiments conducted in ultramafic serpentine soils show high efficiencies in Ni recovery, providing a great potential to implement commercial recovery of Ni from serpentine soils [2].

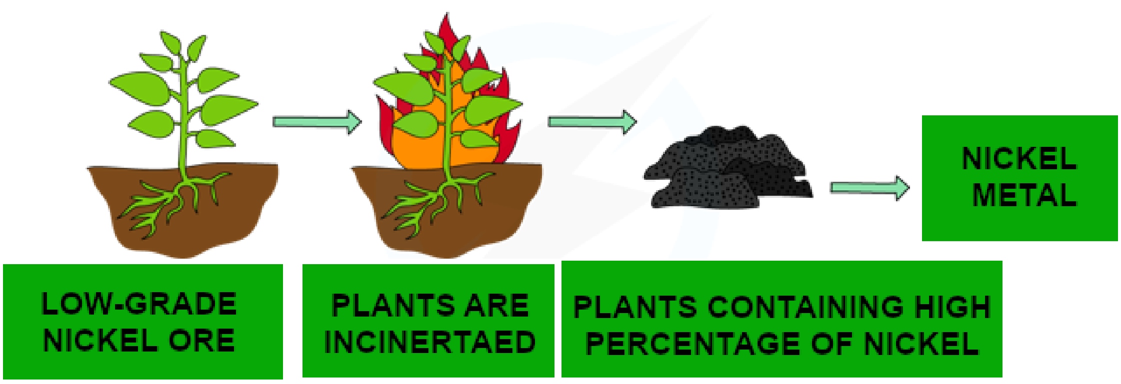

Figure 1: Nickel recovery from the phytomining process

According to the recent estimations of the World Bank, the expected market price for Ni is nearly 22,000 US$/ton. In this context, the bio-ore of Ni hyperaccumulator plants can be employed in producing the purest Ni salts, whereas the market price increases with the purity. Moreover, this approach offer financial revenue for lands with low agricultural potential. For example, Ni phytomining field experiments performed in Albanian ultramafic soils found that the Alyssum murale species produces more than 100 kg of Ni per hectare [5]. However, the profit depends on the cost of cultivation of hyperaccumulators, their hyperaccumulation ability of Ni, the cost of Ni recovery from bio-ore, and the global market price [6].

Serpentine soils distributed in different geographical areas have unique compositions and characteristics with significantly high enrichment of some metals such as Ni, Cr, and Co. Even though serpentinite environments have been disregarded for a long time due to their low fertility and less economic importance, today, they are valued as potential sources for Ni. The global Ni production primarily depends on the high-grade laterite and sulfide deposits where the cut-off grade ranges between 1.5-3 wt%. Among them are a few high-grade deposits with serpentinite origin, such as Sulawesi in Indonesia, Murrin Murrin in Western Australia, and Voisey's Bay in Canada. Nevertheless, current challenges in Ni supply have triggered the Ni phytomining from serpentine soil having a low ore grade between 0.6 and 1.2 wt% [7]. In this regard, phytomining is applied for low-grade high-bulk Ni serpentinite deposits disseminated worldwide to extract Ni effectively.

Sri Lanka also has several serpentinite deposits with high enrichment of Ni, while they are low-grade compared to the commercially exploiting deposits worldwide. However, to date, no phytomining-related studies have been carried out to assess the potential of Ni recovery from these deposits. Therefore, introducing Ni phytomining to the Sri Lankan serpentine soil would be a timely approach to establishing a Ni mining industry in the country to cater to the national economy.

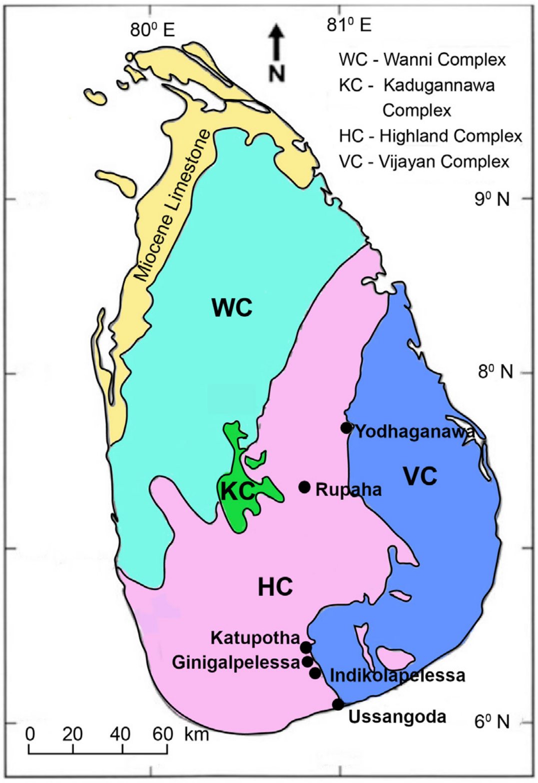

Figure 2: Serpentinite deposits in Sri Lanka

Serpentinite deposits in Sri Lanka

In Sri Lankan geological setting, there are six serpentinite deposits-Ussangoda, Indikolapelessa, Ginigalpelessa, Yodhaganawa, Katupotha, and Rupaha (Figure 2) found along the boundary of Highland and Vijayan complexes. The geochemistry and lithology of these deposits have been well documented in previous literature, highlighting the elevated Ni, Cr, and Co concentrations in both soil and rocks [8]. According to previous studies, the

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average Ni concentration of Sri Lankan serpentine soil varies from 6000 to 8,000 mg/kg, whereas in some deposits, the Ni concentration has exceeded 10,000 mg/kg. Furthermore, geochemical and toxicological studies have identified the toxicity effects on the local ecosystem and human health [9]. However, no remediation or metal recovery practices have been implemented in these deposits. Therefore, to fill this prevailing gap, the phytomining research team of the Department of Earth Resources Engineering, University of Moratuwa, has initiated Ni phytomining trials in the Ginigalpelessa serpentinite deposit in Sri Lanka.

Nickel phytomining trials in Ginigalpelessa serpentinite deposit, Sri Lanka

Ginigalpelessa serpentinite deposit is one of the largest serpentinite deposits located in the Uva province of Sri Lanka. The area extends to about 1 km^2, margined with Sevanagala sugar cane cultivation from the east. The present study has identified several Ni-enriched areas from a geochemical survey of 31 sampling locations with an average Ni content of 8,711 mg/kg. Furthermore, plant diversity and abundance analysis from the current study identified a few Ni toxicity-tolerant species, such as *Pterospermum suberifolium, Apluda mutica, Morinda tinctoria, Vitex pinnata, Tephrosia purpurea,* and *Syzygium cumini* dispersed in highly Ni-enriched areas in the deposit. Among them, Apluda mutica species accumulated 2,270 mg/kg of Ni, exceeding the hyperaccumulation levels. The research team has conducted ex-situ trials as a pilot study for Ni phytomining, using the identified highly abundant plant species in the deposit. Currently, four plant species have been selected for the phytomining trials in serpentine soil. To determine the best Ni hyperaccumulator species, *Brassica juncea*, an introduced species, and three native species identified in the deposit, such as *Apluda mutica*, *Crotalaria sp.*, and *Imperata cylindrica* were planted in pots under different soil amendments (Figure 3). The plants will be harvested when they reach their maximum biomass, and the hyperaccumulator levels will be determined.

The main objective of this study is to identify the best Ni hyperaccumulator species and to develop a proper Ni extraction procedure to recover optimum Ni content from the selected hyperaccumulator species. Therefore, this study provides new insights for the Sri Lankan metal industry to develop a small-scale Ni mining industry from serpentine soil in the future.

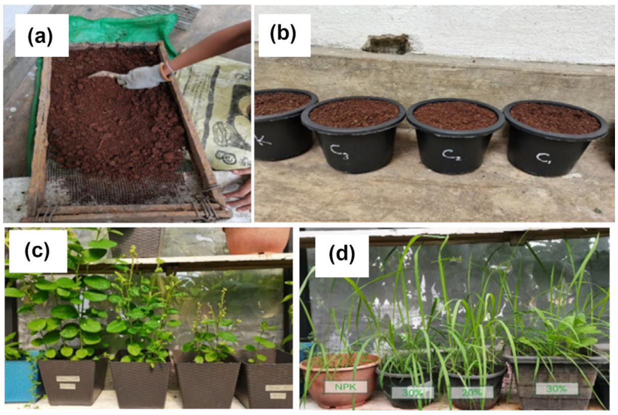

Figure 3: Ni phytomining trials in Ginigalpelessa serpentine soil. (a) Soil media preparation, (b) pot preparation with different soil amendments, and (c) & (d) planting native plant species in the soil (Crotalaria sp. and *Imperata cylindrica*)

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