Assessing the Potential of Critical Metals and Rare Earth Elements in Lateritic Soils of the Southwestern Region of Sri Lanka

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Abstract

Laterites are currently considered potential targets for critical metals (CMs) exploration considering their near-surface occurrence, large dissemination, and enrichment of CMs in lateritic soil during weathering. Although prominent lateritic formations are found in Sri Lankan geological terrain, the potential for CMs has not been explored yet. Therefore, the present study assesses the potential of CMs in laterites of the southwestern part of the country. 60 samples were collected covering the overall study area and processed for critical metal analysis. The metal concentrations of CMs: Al, Ni, V, Cr, As, Sr, Co, Sc, and REEs were determined from inductively coupled plasma-mass spectrometry (ICP-MS) and Li, Fe, and Al concentrations were determined from atomic absorption spectroscopy (AAS). According to the analysis, critical metals such as Cr, V, Ni, and Th were significantly high in laterite samples ranging from 42-419, 116-583.4, 274 – 1498, and 33 – 472 mg/kg, respectively. REE and other critical metals considered in the study including Co and Cu, showed comparatively low potential. The findings of the study emphasise that laterite soil has significant potential for Ni, V, and Cr, especially in low grades. The conclusion is this analysis will benefit future CMs' exploratory investigations by providing insights into the potential of CMs in Sri Lankan laterite deposits.

Keywords: Critical metals, Laterites, REEs, Sri Lanka

1 Introduction

Critical metals (CMs), including rare earth elements (REEs), play a vital role in advanced manufacturing, renewable technologies, and other rapidly emerging industries [1]. Especially, REEs are widely used in high-tech devices such as solar panels, LED lighting, autocatalytic converters, super magnets, and rechargeable batteries [2]. The European Union (EU) classifies these CMs as vital raw resources with a significant risk of supply due to their broad applicability in the aforementioned technological applications [3]. The global demand for CMs has significantly increased over the past few years. For example, from 2017 to 2022, the overall demand for CMs such as Li, Co, and Ni has escalated by 200%, 70%, and 40% [4]. Therefore, exploring new and alternative sources of CMs is essential to maintain a steady and reliable supply in the future.

Laterites are formed by intense subaerial weathering of rocks under tropical and subtropical climates with high enrichment of hydrated iron (Fe) and Al oxides [5] [6]. During the weathering process, CMs such as REEs, PGEs, and Sc tend to concentrate due to residual and secondary enrichment. Considering the near-surface occurrence and large dissemination of laterites make them a worthwhile exploration target [7]. If laterites are derived from CM-hosted rocks, CMs could be highly enriched in the weathered layers, making laterites a viable resource for the CMs [8]. For example, the Mount Weld deposit in Australia, which is hosted by a major primary source of REE which is carbonatite rock, has a 70 m thick laterite layer with significant enrichment of REEs (11.2 wt% REO) and the Moa Bay Ni laterite deposit in Cuba has 50 m thick laterite layer and produces 34.263 t Ni, and 3.792 t of Co [9] [10]. With the increasing demand for these critical metals, currently, global metal production is shifting towards low-grade laterite deposits where there is economic potential for metal recovery.

Sri Lanka is a tropical country with mild temperatures and wet-to-dry seasons throughout the year. Therefore, widely spread thick lateritic soils are evident in Sri Lanka [11]. Particularly, the lateritic formations in the southwestern region of Sri Lanka are more prominent due to abundant rainfall compared to the northern and central regions of the country [12]. Therefore, this study focuses on assessing the potential of CMs, including REEs in lateritic soils of the southwestern region of Sri Lanka.

2 Methodology

2.1 Study Area

The southwestern region (Negombo to Kalutara) of Sri Lanka was selected as the study area for this research. In this area, granite gneiss and charnockite gneiss are the major rock types present and two types of laterites can be found: laterite discontinuous caps and sandy lateritic gravel. Fig. 1 represents the selected sampling locations respective to the geological map of the study area.

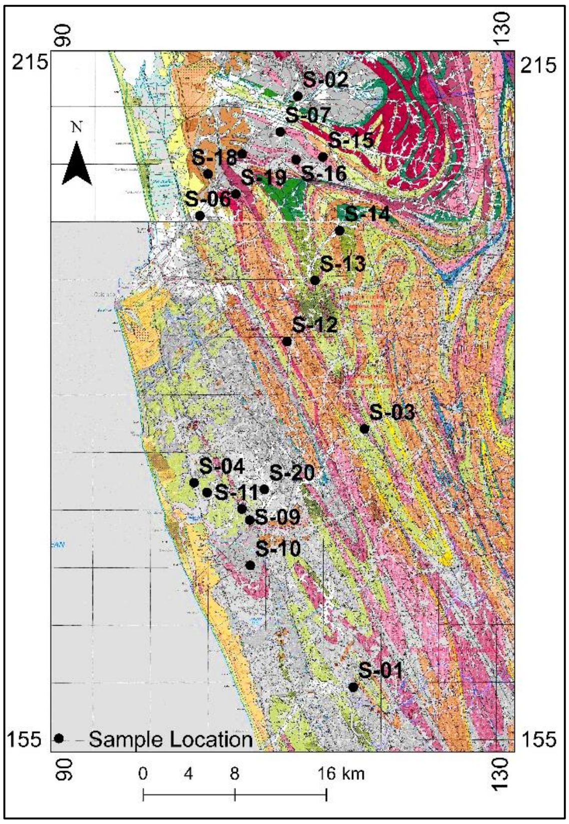

Figure 1: The study area from Kalutara to Negombo with respect to the geological map with the selected sampling locations. Transverse mercator projection. Origin of the projection (7^{0}0001″ N, 80^{0}4618″ E)

2.2 Sample collection and preparation

A total of 60 soil samples were collected from 20 locations representing specific parental rocks, with 3 samples per location. Twenty composite samples were then prepared to represent the lateritic crust at each location. The collected samples were oven-dried at 105^{0}C for 24 hours to remove moisture and crushed into small pieces by the laboratory jaw crusher. Then, they were further grounded by the laboratory Tema mill and sieved through a 63 µm sieve to reduce the particle size to 63 µm. Representative samples were obtained via the coning and quartering methods.

2.3 Critical metal and REE analysis by inductively coupled plasma mass spectrometry

A 0.5 g of each 20 representative samples was digested using a mixture of HNO_3: HCl: H_2O_2 = 1:3:1 and diluted 1000 times. Samples were analysed for CMs (Al, Ni, V, Co, As, Sr, Sc) and REEs using an Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). To maintain the quality of the analysis, international reference samples for ICP-MS (San Joaquin NIST SRM 2709a from Sigma-Aldrich, Germany) were used with three replicates of each sample and an acid-blank sample.

2.4 Iron (Fe) and Lithium (Li) by atomic absorption spectroscopy (AAS)

Considering the major rock types, five representative samples were collected (S-04, S-10, S-13, S-14, and S-19) as each sample from lateritic gravel, garnet sillimanite biotite gneiss, charnockitic gneiss, granite gneiss, and calc gneisses. 0.5 g of each sample was measured for the analysis. Then, they were digested using the same digestion procedure and diluted 100 times using distilled water. The digested samples were analysed for Fe and Li by Atomic Absorption Spectroscopy (AAS). As in the ICP-MS analysis, the quality of the analysis was improved using three replicates and acid-blank samples.

3 Results and discussion

3.1 Fe and Al contents

Table 1 shows the Al and Fe contents of five selected samples. Accordingly, Fe content in the studied lateritic soils is higher than Al, indicating that it is in ferrugenic nature and not in bauxite composition. Laterite soil typically develops in areas where the parent rock is rich in alumina, iron, and silica resulting in its distinct characteristic of having a significant presence of Al and Fe content [13].

Table 1: Al and Fe content of selected samples

Sample	Al (%)	Fe (%)	Rock type
S 04	3.531	9.711	Lateritic gravel
S 10	7.782	15.086	Granite gneiss
S 13	6.632	7.386	Calc-gneisses
S 14	4.446	7.731	Garnet sillimanite biotite gneiss
S 19	5.828	14.941	Charnockitic gneiss

The highest concentrations of Al and Fe are possessed by the major rock types identified in the study area; granite gneiss and charnockitic gneiss. The crustal abundance of Al is 15.4% and the cut-off grade is 44 wt.% [14] [15]. In addition, a higher concentration of Fe weathering has resulted from the granite gneiss.

3.2 Enrichment of CMs

Table 2 represents the analytical results obtained for the studied laterite samples revealing a range of noteworthy values. Cr, V and Ni showed high concentrations ranging from 42 - 419 mg/kg, 116 - 583.4 mg/kg, and 274 – 1498 mg/ kg respectively. Th concentrations of the samples varied from 33 to 472 mg/kg, indicating the occurrence of these radioactive elements in laterites. Other critical metals considered in the study such as Co, As and Sr showed relatively low concentrations ranging from 0.6 – 10.8, 10.3 – 42.1, and 0.5-26.2 mg/kg. The total REE concentration ranges from 41.6 to 194 mg/kg while the light rare earth elements (LREE) and heavy rare earth elements (HREE) range from 15.5 – 104 mg/kg and 6.6 – 44.1 mg/kg, respectively.

The order of critical metal average concentrations of the samples is Ni > V > Cr > As > Sr > Co. HREE are considered by including Y. The order of average concentrations in REE in the samples are Sc > Ce > Gd > Nd > La > Sm > Y > Dy > Pr > Er > Tb > Yb. Furthermore, Ho, Tm and Lu showed the lowest result below the level of 1000 ppb.

Fig. 2 represents the chondrite normalised patterns for each sample. The chondrite normalised graph indicates an upward spike in Eu – Dy, a higher concentration than the upper continental crust (UCC) values and a significant downward spike in Lu in each sample location. All the laterite samples denoted a downward trend in REE composition.

3.3 Economic significance of laterites as a source for CMs

The samples have significant concentrations of critical metals like V, Ni, and Cr and showed a significant Th radioactive metal concentration in the samples. Therefore, these sample locations can be identified as potential sources for low-grade critical metal deposits.

With the development surge of critical metal-based applications, extraction of these metals has become crucial. Hence, using low-grade mining techniques like phyto-mining and bioleaching will be economically viable in the future [16].

Table 2: Concentrations of CMs (mg/kg) in lateritic soils of the southwestern region of Sri Lanka

Location	Al	V	Cr	Ni	Co	As	Sr	Th	Ga	REE
S01	78209.05	344	42	1108.8	4.8	15.8	11.7	10.8	39.7	194.3
S02	29562.26	521.2	267.3	1124.8	2	27.4	14.7	42.9	34.8	90
S03	68474.2	452.3	362.6	935.8	1.9	12.1	9.8	43.3	31.5	63.1
S04	35312.6	337.4	266.8	989.5	1.6	22.5	20.6	47.1	32.4	51.4
S05	44364.09	583.4	385.4	1192.5	1.4	34.5	11.3	113.6	40.3	50.7
S06	46851.12	408.7	418.8	1350	1.6	30.3	16.2	87.4	34.6	62.5
S07	47952.97	458.3	322.9	1497.6	1.8	32.8	17.6	97.1	33.0	66.6
S08	72350.38	234.1	129.7	849.5	1.1	14.4	26.2	157.7	86.9	153.9
S09	78209.05	256.0	104.9	749.7	2.4	22.2	9.6	69.0	75.0	55.4
S10	78209.05	333.8	122.5	914.5	2.0	20.4	24.7	66.6	73.9	145.2
S11	78209.05	260.8	108.6	649.1	1.0	23.4	10.8	113.3	72.0	74
S12	77823.87	274.2	93.7	659.2	10.8	18.8	5.3	53.5	50.3	109.8
S13	66324.71	161.6	42.2	274.3	0.6	4.7	0.5	104.6	29.9	49.4
S14	44461.01	168.6	135.6	563.6	1.5	10.0	4.0	97.4	49.6	97.8
S15	33026.58	268.4	68.2	280.9	0.7	4.9	2.2	34.9	30.2	45.8
S16	78170.62	226.2	78.0	316.0	0.6	6.0	1.8	56.0	47.9	43.3
S17	67018.85	116.3	128.3	487.0	0.7	8.5	2.3	125.5	47.2	83.3
S18	22925.3	213.9	112.8	834.8	8.0	17.6	4.3	45.2	28.2	136
S19	58283.06	171.3	146.8	503.6	1.0	6.0	2.9	24.6	38.5	81.6
S20	63749.67	136.3	131.4	461.5	0.8	14.6	5.1	38.1	46.6	41.6

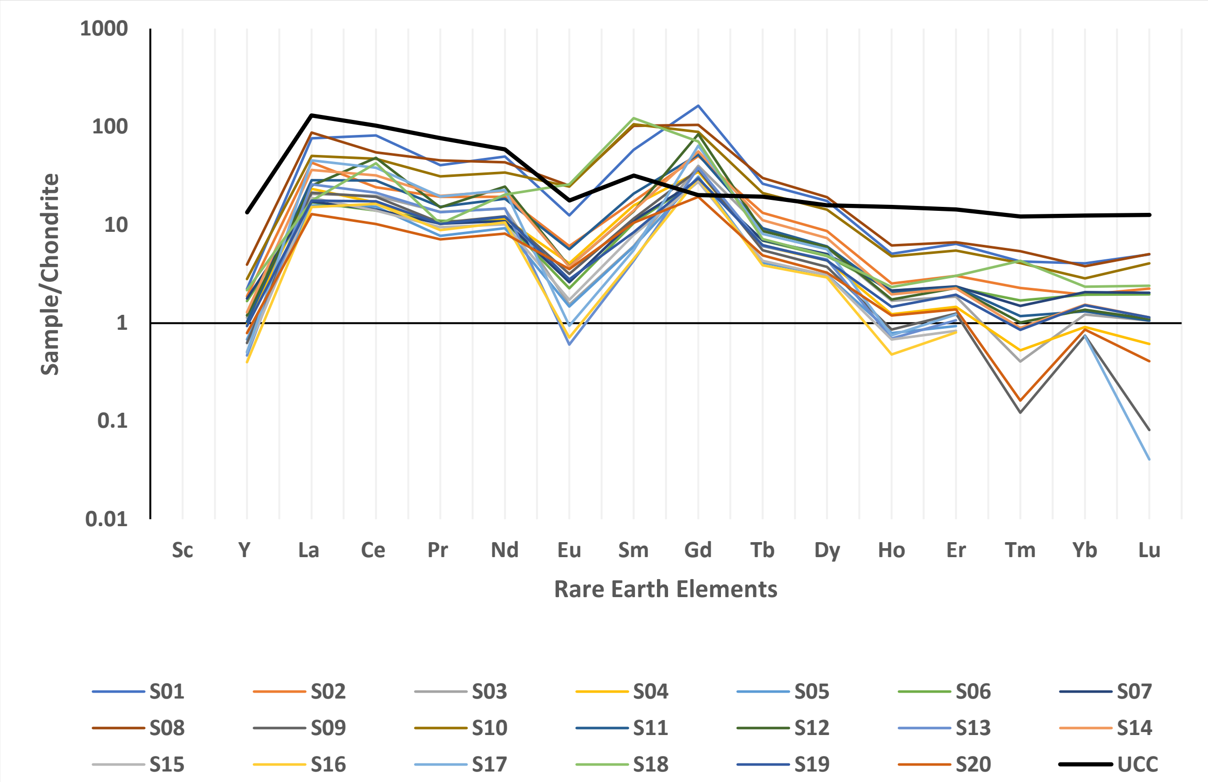

Figure 2: Chondrite normalised patterns for REE in 20 locations and UCC values

5 Conclusion

This study reveals that lateritic soils of the southwestern region in Sri Lanka have high contents of several critical metals, namely V (270 mg/kg), Cr (140 mg/kg), Ni (704 mg/kg), Th (107 mg/kg) and minor contents of Co, Cu and As. Therefore, these highly concentrated metals can be extracted from laterite by implementing a proper extraction procedure. The presence of these metals in laterites provides insight into conducting more detailed studies for the southwestern area to explore possible laterite deposits enriched with these metals. However, the findings of the occurrence of other valuable metals like REEs are considerably low with about 85 mg/kg value in laterites. Therefore, lateralization caused by weathering does not essentially enrich the REE concentration. Since there are limited studies in laterite deposits of Sri Lanka, the findings of this study would be a groundwork for the recovery of the critical metals from laterites, as a low-grade source in Sri Lanka.

Acknowledgements

The authors are thankful to the Instrument Center of the University of Sri Jayawardenapura for helping with sample analysis.

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