Assessment of Rare Earth Element Potential in Intrusive Rocks Special Reference to Massenna Zircon Granite

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Abstract

Sri Lanka has a geological setting that favors the presence of rare earth elements (REEs), which are currently identified as the most critical and strategic elements in the world. Previous geochemical studies show that intrusive rocks, such as carbonatites, pegmatites and granitoid rocks could be enriched of REEs. Therefore, this research is focused on assessing the REE potential in pegmatites with special reference to the zircon granite in Massenna. The collected samples from the focused areas were subjected for XRD analysis and monazite, apatite, allanite, bastnaesite, and loparite were found as the major RE minerals. Moreover, Massenna zircon granite has the highest REE potential, particularly LREEs and Y, compared to other pegmatites. The presence of REEs in the in-situ soil and sediment samples indicate that, REEs have been transported through weathering and erosion processes of the zircon granite, thus proving the REE potential in the source rock. Furthermore, REEs are mostly associated with felsic minerals rather than mafic minerals. Therefore, this research clearly provides insights of REE potential in the pegmatite bodies in Sri Lanka and more REE explorations need to be carried out in these prospects.

Keywords: Balangoda, Pegmatite, Rare Earth Bearing Minerals, Sri Lanka, XRD Analysis

1. Introduction

Rare earth elements (REEs) are a group of seventeen elements in the periodic table, including the fifteen lanthanides plus yttrium and scandium. Mainly, REEs are categorized into two types, light rare earth elements(LREEs) and heavy rare earth elements(HREEs).During the last three decades, REEs have been extensively used in high-tech and green technologies, such as rechargeable batteries, autocatalytic converters, super magnets, fluorescent materials, and solar panels due to their unique physical, chemical, and luminescent properties[1]. Rare earth element (REE) deposits are divided into two major categories as primary and secondary deposits. Primary deposits (e.g. metamorphic rocks, pegmatites, carbonatites, and hydrothermal veins) are formed by magmatic, hydrothermal or metamorphic processes, whereas secondary deposits (e.g. placers, laterites, and ion-adsorption clays) are formed by erosion and weathering of the primary deposits [2]. More than 250 rare earth (RE)-bearing minerals have been identified to date and the most common RE-bearing minerals are bastnaesite, monazite, and xenotime [3].

Continuously increasing demand of REEs with the development of high-tech and green technologies and the lack of REE sources may result a REE scarcity in near future. Currently, countries, such as China, USA, Brazil, Canada, and Russia are the main producers of REEs, while China holds the monopoly over global REE supply for the last few decades [1]. This China's monopoly over REE supply results in REE price fluctuations and less reliable REE market. Therefore, many countries are now engaged in exploring new and alternative sources of REEs as a solution to the triggered REE scarcity resulted by the ever-increasing demand for REEs [4].

Based on the previous geochemical and mineralogical studies, in the Sri Lankan terrain, RE-bearing minerals are mostly found in the deposits, such as carbonatites, pegmatites, and beach and alluvial placers. The most well-known deposits with high potential of REEs are Eppawala carbonatite and Pulmoddai mineral sand deposits [5], [6]. In addition, pegmatite bodies in Balangoda and Matale areas, gem-bearing alluvial placer deposits in Rathnapura, Elahera, and Walawe gem fields, and beach placer deposits are also considered as potential REE prospects in Sri Lanka [7]. However, only a few geochemical studies and no REE prospecting studies have been carried out in these geological formations, to date. Particularly, no published literature is available for the REE potential in granitic rocks in Sri Lanka. Therefore, more detailed REE prospecting studies must be carried out in these deposits since due to escalating REE demand and the development of new techniques for REE extraction, low-grade ores are also becoming economical exploitable targets.

2. Methodology

A total of 18 rock samples were collected from pegmatite bodies in Balangoda and Matale/Kandy areas, whereas 8 out of them are from zircon granite in Massenna area, Balangoda. In addition, 4 in-situ soil and 3 sediment samples were collected from the close vicinity of the pegmatite bodies (Table 1).

Location	Type of Sample	Symbol	Coordinate	
			N	E
Balangoda	Soil	S1	6.664	80.647
Balangoda	Soil	S2	6.664	80.647
Balangoda	Soil	S3	6.665	80.647
Balangoda	Soil	S4	6.665	80.648
Balangoda	Sediments	SE1	6.665	80.648
Balangoda	Sediments	SE1	6.665	80.648
Balangoda	Sediments	SE3	6.661	80.656
Galaha	Rock	R1	7.218	80.669
Oman Lanka	Rock	R1	7.511	80.662
Kaikawala	Rock	R1	7.505	80.655
Kaikawala	Rock	R2	7.505	80.655
Kaikawala	Rock	R3	7.505	80.655
Kinchigune	Rock	R1	6.703	80.782
Kinchigune	Soil	S1	6.703	80.782
Rajawaka	Rock	R1	6.646	80.865
Seelogama	Rock	R1	6.696	80.776
Seelogama	Soil	S1	6.696	80.776

Table 1: Sampling Locations

First, smooth flat horizontal surfaces at the center of each rock samples were prepared using a rock cutter and minerals were visually identified by observing the flat surface of the rock samples using hand lens. After drying the samples in an oven at a temperature of 110–180 ^{0}C for 8–10 hours, all the samples were powdered using the laboratory tema mill to reduce the average grain size. Powdered samples were then sieved using 63 microns sieve. Sample fractions lesser than 63 microns were analyzed by X-ray diffraction method using BRUKER D8 advance eco X-ray diffractometer.

3. Results

After the visual observation of rock samples, felsic minerals (quartz and feldspar) and mafic minerals (hornblende, pyroxene, etc.) were identified in the Massenna zircon granite and felsic to mafic ratios were calculated for each rock samples. Results obtained by visual observations of Massenna rock samples are shown in Table 2.

Variation of felsic to mafic ratio with the number of REE-bearing minerals present in the samples indicates a trend line with 0.0667 linear regressions (Figure 1). Moreover, variation of felsic to mafic ratio with the number of REEs present in the samples shows a trend line with 0.0745 linear regression value (Figure 2). In addition, graphite, pyrite, biotite, phlogopite mica, hornblende, hypersthene, calcite, and pyroxene were identified as accessory minerals in the Massenna zircon granite.

Table 2: Results obtained from visual verification of zircon granitic rock samples

Sample Name	Mineral Type	Minerals Present	Mineral Percentage	Quartz/ Feldspar Ratio	Felsic/ Mafic Ratio
R1	Felsic	Quartz	35% - 40%	0.889	7.083
		Feldspar	40% - 45%		
	Mafic		10% - 12%		
	Accessory Minerals	Graphite, Pyrite			
R2	Felsic	Quartz	40%	0.889	5.667
		Feldspar	45%		
	Mafic		12% - 15%		
	Accessory Minerals				
R3	Felsic	Quartz	35%	0.875	3.750
		Feldspar	30% - 40%		
	Mafic	Hornblend, Pyroxene, Phlogopite	20%		
	Accessory Minerals	Pyrite, Biotite			
R4	Felsic	Quartz	35%	1.167	2.600
		Feldspar	30%		
	Mafic		20% - 25%		
	Accessory Minerals	Pyrite, Phlogopite mica			
R5	Felsic	Quartz	35% - 40%	0.889	7.083
		Feldspar	35% - 45%		
	Mafic		10% - 12%		
	Accessory Minerals	Hornblend, Pyroxene, Calcite, Hypersthene			
R6	Felsic	Quartz	30% - 35%	0.700	5.667
		Feldspar	40% - 50%		
	Mafic		12% - 15%		
	Accessory Minerals	Hornblend, Pyroxene, Calcite			
R7	Felsic	Quartz	35% - 40%	0.889	4.722
		Feldspar	40% - 45%		
	Mafic	Biotite rich	15% - 18%		
	Accessory Minerals	Hornblend, Graphite, Pyroxene, No Pyrite			
R8	Felsic	Quartz	40% - 45%	1.125	5.667
		Feldspar	40%		
	Mafic	Phlogopite mica	12% - 15%		

Accessory Minerals	Biotite, graphite, Hornblend, Pyroxene

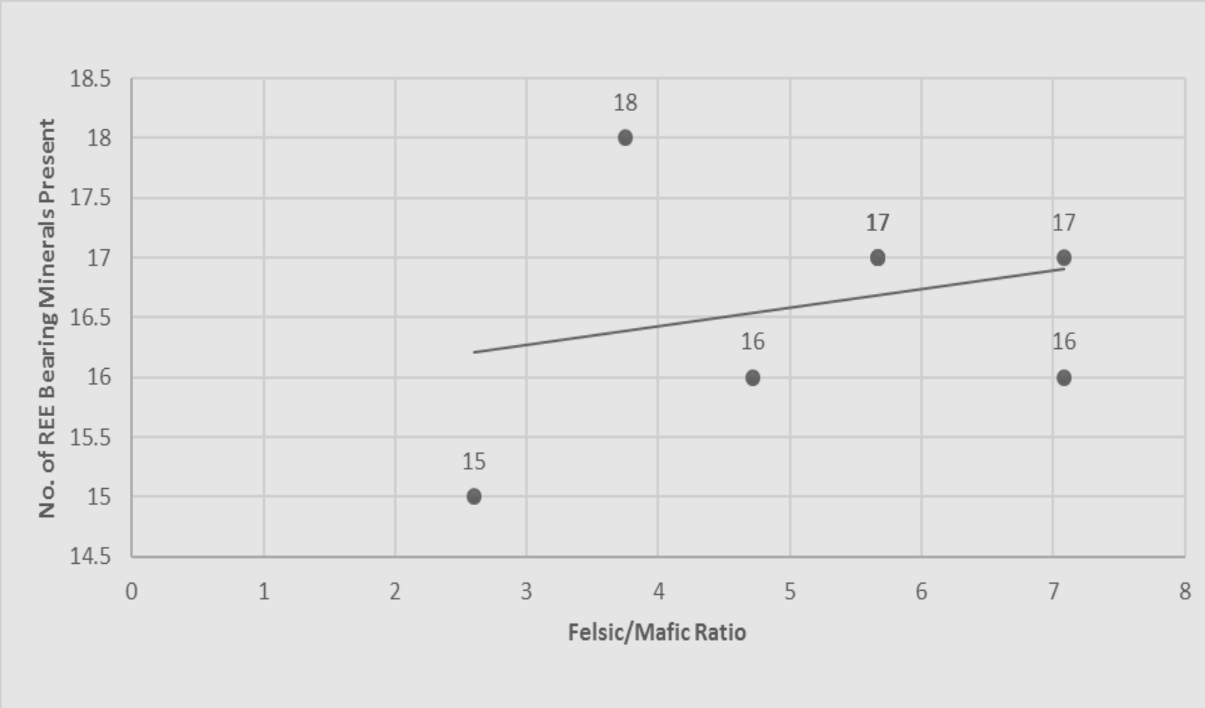

Figure 1: Graph of felsic to mafic ratio vs number of REE bearing minerals present in zircon granite *(Out of 18 number of total REE bearing minerals, number of REE bearing minerals present in the sample used for the vertical axis. REE bearing minerals present in each sample shown in Table 3)*

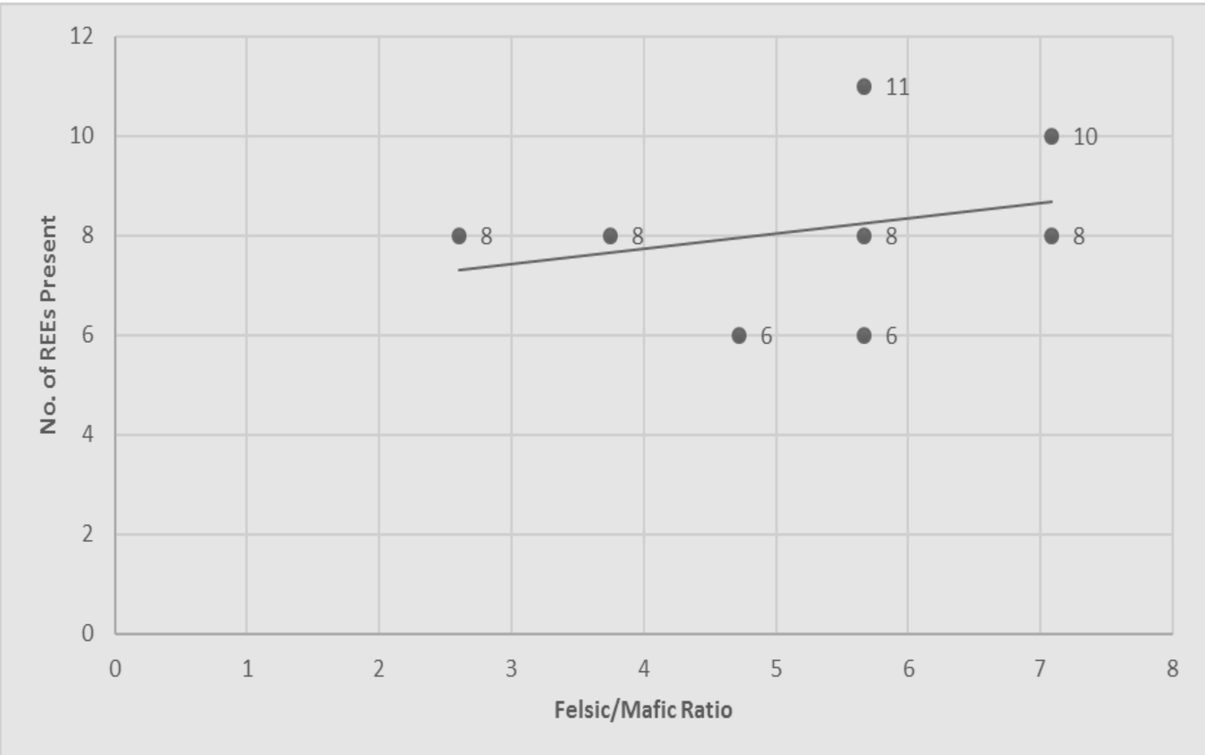

Figure 2: Graph of felsic to mafic ratio vs number of REE in zircon granite *(Out of 17 number of total REEs, number of REEs present in the sample used for the vertical axis. REEs present in each sample shown in Table 4)*

Table 3 shows identified minerals using XRD analysis and based on this table most of the REE-bearing minerals are present in all the samples. Moreover, Table 4 includes REEs that present in each sample. According to the results in Table 4, all 25 samples contain La and Ce, whereas Nd and Y present in most of the samples. Furthermore, average number of REEs present in the samples out of 17 elements in different locations shown in Table 5.

Table 3: Results of XRD analysis for rare earth bearing minerals *(√Mark shows the presence of RE bearing mineral)*

Location	Sample Type	Sample No	Allanite	Apatite	Bastnaesite	Eudialyte	Fergusonite	Gittinsite	Iimoriite	Kainosite	Loparite	Monazite	Mosandrite	Parisite	Pyrochlore	Rinkite (Rinkolite)	Steenstrupine	Synchysite	Xenotime	Zircon
Massenna Granite	Rock	R1	√	√	√	√	√	√		√	√	√	√	√		√	√	√	√	√
		R2	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√
		R3	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
		R4	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√		
		R5	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√
		R6	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√
		R7	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	
		R8	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Soil	S1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
		S2	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
		S3		√	√	√	√	√	√	√	√	√	√	√		√		√	√	√
		S4	√	√			√			√	√	√	√		√	√			√	√
	Sediments	SE1	√	√			√			√	√	√	√		√	√			√	√
		SE2	√	√	√	√	√		√	√	√	√	√	√		√	√	√	√	
		SE3	√	√			√			√	√	√	√		√	√			√	√
Galaha	Rock	R1	√	√	√	√	√	√	√	√	√	√	√	√		√	√			√
Oman Lanka	Rock	R1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Kaikawala	Rock	R1		√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√
		R2	√	√	√		√	√	√	√	√	√	√		√	√	√	√	√	√
		R3	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Kinchigune	Rock	R1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√
	Soil	S1	√	√	√	√	√	√	√	√	√	√	√	√	√		√		√	√
Rajawaka	Rock	R1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Seelogama	Rock	R1	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
	Soil	S1	√	√	√	√	√	√	√	√	√	√	√	√	√		√		√	√

Table 4: Results of XRD analysis for rare earth elements *(√Mark shows the presence of REE)*

Location	Sample Type	Sample	Sc	Y	La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Massenna Granite	Rock	R1		√	√	√	√	√		√		√		√		√		√	
		R2		√	√	√	√	√		√	√	√							
		R3		√	√	√	√	√		√	√	√							
		R4		√	√	√	√	√		√		√						√	
		R5		√	√	√	√	√		√		√							√
		R6		√	√	√	√	√										√	
		R7		√	√	√	√	√					√						
		R8		√	√	√	√	√		√		√		√		√		√	√
	Soil	S1		√	√	√	√	√		√		√						√	√
		S2		√	√	√	√	√		√		√		√	√				
		S3		√	√	√	√	√		√		√							√
		S4		√	√	√		√		√			√	√				√	
	Sedi ments	SE1		√	√	√	√	√		√		√	√	√				√	
		SE2		√	√	√	√	√		√		√		√		√		√	
		SE3		√	√	√	√	√		√		√	√	√				√	
Galaha	Rock	R1		√	√	√	√	√			√								
Oman Lanka	Rock	R1			√	√		√							√				
Kaikawala	Rock	R1		√	√	√	√	√		√		√							√
		R2		√	√	√		√											√
		R3		√	√	√	√	√		√	√	√							√
Kinchigune	Rock	R1		√	√	√						√							
	Soil	S1		√	√	√		√											√
Rajawaka	Rock	R1		√	√	√	√	√		√	√	√			√				
Seelogama	Rock	R1		√	√	√	√	√			√								√
	Soil	S1		√	√	√	√	√			√								

Table 5: Out of total 17 REEs, identified number of REEs present in samples at different locations as a percentage

Sampling Location	Average number of REEs present in samples out of 17 REEs
Massenna Granite	50.58%
Galaha	29.41%
Kaikawala	43.11%
Kinchigune	26.47%
Rajawaka	52.94%
Seelogama	38.23%

4. Discussion

According to the XRD analysis of the rock samples in zircon granite, most of REEs are present in the samples. La, Ce, Pr, Nd and other LREEs are mostly associated with zircon granite than other REEs. However, in regard of HREE content, only Y has a higher potential in this source rock. Therefore, Masssenna zircon granite is mainly abundant in LREEs & Y. Therefore, it can be concluded that Massenna zircon granite is a good source rock for LREEs along with Y.

In addition, in-situ soil and sediment samples in the close vicinity of the source rock also contain REEs. Therefore, in-situ soil and sediments associated with pegmatites can also act as sources for REEs. Due to the presence of REEs in the in-situ soils and sediments, it can be concluded that REEs has transported by weathering and erosion processes of the zircon granite to the in-situ soils and stream sediments.

Based on the analysis of results obtained from visual verification of minerals in the rock samples using hand lenses, a relationship was derived between felsic to mafic ration and present REEs. It is that, as the felsic to mafic ratio increases, the number of REE-bearing minerals and the number REEs present in the samples also increases in Massenna zircon granite. Therefore, in conclusion, REEs are mainly associated with felsic minerals rather than mafic minerals in Massenna zircon granite. When comparing the REE potential in different locations (Kinchigune, Galaha, Seelogama and Kaikawala) with Balangoda Massenna, Massenna area has the higher potential than others except Rajawaka. In addition to Massenna granite, a good REE potential was identified in Rajawaka area.

5. Conclusions

Among the pegmatites that were studied in this research, Massenna zircon granite can be considered as a good source rock for REEs compared to other pegmatites, especially, for LREEs and Y. In addition, pegmatites located in Rajawaka area also have higher potential for REEs. Moreover, in-situ soil and sediments in the surrounding area of the Massenna granite are enriched of REEs and they have been transported by weathering and erosion processes. Furthermore, REEs are mostly associated with felsic minerals than mafic minerals in the Massenna granite.

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