



An overview on the possibility of scandium and REE occurrence in Sulawesi, Indonesia

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Abstract

This manuscript reports an overview on the possibility of scandium and rare earth element occurrence in Sulawesi. Development in modern-high technology application is growing rapidly, resulting constant supply of critical metal and rare earth elements (REE). Currently, resources of these elements are restricted and new source of these elements need to be discovered accordingly. Scandium (Sc) as one of the critical metals is an important metal for electrolyte of solid oxide fuel cells and others advance technology. In addition, REE is an important element in the use of permanent magnets and rechargeable batteries. Recent work reported that scandium can be extracted from weathering crust of highly weathered nickel-contained ultramafic rock. Scandium will be concentrated in limonite and saprolite layer, but the volume of enrichment is still unknown. REE found in granitic rocks particularly in zircon, monazite and xenotime and it has been reported that rare earth ore were extracted from heavily weathered granitic rocks. Sulawesi is one of the islands where lateritic deposits from heavily weathered ultramafic and granitic rocks are widely distributed. The lateritic soil of the ultramafic rocks can be potential source of scandium and the granitic rocks could be the potential source of rare earth element.

Keywords : Scandium, rare earth element, Sulawesi, Indonesia.

Introduction

Rare metals, including scandium and REE, have become a critical issue due to their dramatic increase in industrial use as well as their rarity. Scandium (Sc) is an important metal for electrolyte of solid oxide fuel cells and the demand is likely to increase in the near future. In addition, REE is an important element in the use of permanent magnets and rechargeable batteries.

Scandium is usually found only in two different kinds of ores. Thortveitite is the primary source of scandium with uranium mill tailings by-products also being an important source. World productions amount to only 50 kg per year. There is no estimate of how much is potentially available.

REE is heavily dependent on some weathered crust deposits in China (ex. Bayan Obo Deposit and highly weathered granitic rock from Southern China). These conditions have led to the growing concern that the world may soon face a shortage of scandium and rare earth elements resources. Therefore, other sources of scandium and rare earth elements are expected to be developed in

order to balance supply and demand of them. However, little attention has been paid to the genesis of Sc-bearing deposits and REE in the world, particularly in Indonesia. In this study, we report an overview of potential distribution of Sc and REE in Indonesia, particularly in Sulawesi.

As Sc is a compatible element, mafic rocks generally have higher Sc contents. Scandium is incorporated into pyroxene (or amphibole) but is rarely contained in olivine. Thus, pyroxenite has higher Sc contents than peridotite. In the process of chemical weathering, Sc is immobile and other mobile elements are leached away. As a result, laterite becomes enriched in Sc. Whole-rock compositions indicate that Sc is likely to substitute Fe³⁺, Al³⁺, Ti³⁺ and other sites in laterites. The Peridotite as a host of Sc-bearing mineral is largely distributed in Sulawesi. However, study in the Sc occurrence in Sulawesi has never been conducted. Meanwhile, one of the most promising sources of REE is granitic rocks as reported by previous studies (Murakami & Ishihara, 2008). This rock is widely distributed in Sulawesi Island, covering

almost 20% of the island (Maulana, 2013). However, report on the occurrence of rare earth elements from this rock is still lacking despite its important economic value.

Scandium

Scandium is used as additives to alloys and electrolytes of a certain fuel cell. A very small amount of Sc has been produced from a variety of ore deposits in the world as a by-product, and few previous studies discussed the economic Sc mineralization except for pegmatite. In recent years, Sc is expected to be produced from lateritic Ni deposits in some countries. Ultramafic rocks form nickel laterites by weathering in the high-latitude region (e.g., Indonesia), because numerous previous study data indicated that Ni²⁺ is generally incorporated into mafic minerals in magma and that they are easily altered by soil or ground water. The previous studies indicate that Sc³⁺ is also contained in mafic minerals such as pyroxene, amphibole and magnetite, but significantly less Sc is contained in olivine.

Nickel laterites can be divided into saprolite ores and limonite ores. The saprolite ores with economic grade of Ni are characterized by garnierite and smectite, whereas the limonite ores rich in Fe oxyhydroxides contain less Ni. Scandium is more or less rich in saprolite and limonite ores, however Sc-bearing minerals in these laterites are not well understood. Whole-rock geochemical data of the laterites suggest that Sc is likely to exist in Fe oxides, Fe oxyhydroxides, Ti oxide, Al hydroxides and serpentine. Scandium is unlikely to be adsorbed on minerals and amorphous materials in the laterites. Scandium is more distributed in pyroxene and amphibole than in olivine in mafic magma since coefficient value of scandium is hosted in orthopyroxene and clinopyroxene as listed in Table 1. It is very likely that low-grade Ni laterite maybe rich in Sc.

Table 1. Partition coefficient value of some minerals

Partition coefficient	Mineral	Rock type	Method	Reference
0.14-0.22	Olivine	Basalt	Phenocryst and matrix	Leeman and Scheidegger (1977)
1.23, 2.82	Orthopyroxene	Basalt	Phenocryst and matrix	Onuma et al. (1968)
2.5 - 3.5	Clinopyroxene	Basalt and andesite	Phenocryst and matrix	Ewart et al. (1973)
2.18	Amphibole	Basalt	Phenocryst and matrix	Higashi and Nagasawa (1969)
0.008	Plagioclase	Basalt	Experiment	Paster et al. (1974)
1.96	Magnetite	Basalt, andesite and dacite	Phenocryst and matrix	Okamoto (1979)
1.8	Ilmenite	Basalt	Experiment	Paster et al. (1974)

Rare earth element

Rare earth elements mineralization occur in some deposit types; e.g. carbonatite rock formation, granitic rocks, manganese deposit, hydrothermal iron-ore deposit, placer deposit, lateritic soil, ion adsorption weathering crust and uranium deposit (Murakami & Ishihara, 2008). One of the most promising sources of these elements is granitic rocks as reported by previous studies (Murakami & Ishihara, 2008). Source of REE is heavily dependent on some weathered crust deposits in China (ex. Bayan Obo Deposit and highly weathered granitic rock from Southern China) which has recently imposed restrictions on their import.

REEs have been produced in increasing quantities in recent years from surficial clay deposits in southern China, and Orris and Grauch (2002) list 18 Chinese occurrences of such material. In 1992, REEs from these deposits comprised 14% of Chinese production (Wu, Yuan, and Bai 1996), and this source has had a strong impact on yttrium supplies since 1988. The deposits reportedly form weathering crusts over granite (Wu, Yuan, and Bai 1996). The ore, referred to as REE-bearing ionic absorption clay, mostly comes from two sites in Jiangxi Province Longnan and Xunwu, the former yielding HREE- and yttrium-rich material and the other, LREE-rich material (O'Driscoll 2003). Ore from Longnan has an HREE-dominated distribution pattern very similar to that of xenotime, whereas ore from Xunwu is relatively enriched in lanthanum (Hedrick 1992). Both ores have relatively low cerium content, suggesting deposition from REE-bearing groundwater with depleted cerium that results from the element's insolubility in the oxidized (Ce+4) state. The ore bodies are 3 to 10 m thick and occur mainly in a wholly weathered zone composed of halloysite and kaolinite with residual quartz and feldspar; grades are reported at 0.05% to 0.2% REOs (Wu, Yuan, and Bai 1996). The deposits are considered to be laterites and show similarities to a number of other lateritic deposits formed over alkaline igneous rocks and carbonatite (Morteani and Preinfalk 1996).

REE deposit from lateritic deposit

REE deposit from lateritic deposit is well known as ionic type deposit or ion adsorption type deposit. Following are the typical characteristic of



ionic type deposit from well-known REE deposit in southern China, particularly Jiangxi Province (Zhang et al, 1996).

1. Geologic Setting of ionic type REE Deposit.

The deposits occur in the weathering crust of granites which supply the REE source for mineralization. The moisture and rainy climate in near subtropic zone provide a suitable condition for REE to be transferred and concentrated in the weathering crust of granites which are rich in REE

2. Mineralizing characteristic of ionic type REE deposits.

The so-called ionic type deposits are the weathering crust of granitoid. After weathering and decomposition of granitoids, REE are released from them and hosted in the weathering crust as ionic form. From the top to bottom the weathering crust can be divided into: (a) humus layer which are several centimeter thick; (b) eluvium and slide rock which are 1 – 2 meter thick; (c) completely weathered layer whose thickness is usually about 5 – 10 meters and the thickest is about 20 meters; (d) semi-weathered layer which is 3 – 5 m thick; (e) bedrock granitoids.

3. Mineral compositions of ionic type REE deposits

(1) Supporter minerals for REE ions in the weathering crust of granitoids.

At present, studies show that all supporter minerals for REE ions are clay minerals, most of which are kaolinite and halloysite. Both of them are polymorph of $Al_2SiO_5(OH_4)$ (Table 2). Two kind of halloysite exist; with and without water in the structural layer. The other clay mineral in the weathered crust of granitoids are montmorillonite, gibbsite, hydrobiotite which is mixture of biotite and vermiculite.

(2) Primary RE minerals

The primary RE minerals (Table 3) are hosted in granitoids. Under weathering conditions, some of them are resistant to weathering, some semi-weathered and some completely weathered and disappear.

Table 2 Chemical compositions (%) of some clay minerals and rock-forming minerals in the weathering crust of granites, Gannan, Jiangxi Province (Zhang et al., 1996)

	Kaolinite (Gannan)	Muscovite (standard)	K.feldspar (standard)	Kaolinite (standard)	Halloysite (water-bearing)	Halloysite (standard)
SiO ₂	46.8	45.2	64.7	46.0	48.44	48.0
Al ₂ O ₃	37.41	38.5	18.4	41.2	33.93	41.2
Fe ₂ O ₃	0.24				0.23	
MnO	0.46				0.56	
CaO	0.29				0.17	
K ₂ O	2.45	11.8	16.9		0.975	
Na ₂ O	0.05				0.10	
H ₂ O ⁺		4.5		10.8		10.8
H ₂ O ⁻	2.50				4.82	
Ignition loss	15.32				11.135	
Total	100.64	100.0	100.0	100.0	99.86	100.0

Table 3 Primary RE and rare elements minerals in ionic type REE deposits from Southern Jiangxi

I Oxide minerals	
(I) Titano-aeschynite-(Y), RE ₂ O ₃ 32.46 – 34.75 %	
(II) Pyrochlore-(Pb), RE ₂ O ₃ 6.68 % , (Nb, Ta) ₂ O ₅ 37.63 – 54.90 %	
(III) Columbotantalite, (Nb, Ta) ₂ O ₅ 70 %	
II Fluorite minerals	
(IV) REE-bearing fluorite, RE ₂ O ₃ 1 %	
III Carbonate minerals	
(V) Synchysite-(Y), RE ₂ O ₃ 46.9 %	
(VI) Parisite-(Y), RE ₂ O ₃ 46.9 %	
IV Phosphate minerals	
(VII) Xenotime, RE ₂ O ₃ 59.87 – 72.40 %	
(VIII) Monazite, RE ₂ O ₃ 58.67 – 60.69 %	
(IX) Rhabdophane-(La), RE ₂ O ₃ 46.88 %	
V Arsenate mineral	
(X) Chernovite, RE ₂ O ₃ 46.90 – 47.61 %	
VI Silicate minerals	
(XI) Allanite, RE ₂ O ₃ 10 %	
(XII) Brithorite, RE ₂ O ₃ 62 %	
(XIII) Thorite, RE ₂ O ₃ little and ThO ₂ >70 %	
(XIV) Zircon, RE ₂ O ₃ little and (Zr, Hf)O ₂ 67 %	

Discussion

Distribution and possible occurrence

1. Scandium

Sulawesi Island is located in the central part of the Indonesian archipelago, which consists of four tectonic provinces (Kadarusman et al., 2004; Maulana, 2009): (1) the West and North Sulawesi

Pluto-Volcanic Arc in the south and north arms of the island, (2) the Central Sulawesi Metamorphic Belt, extending from the centre of the island to the southeastern arm, (3) the East Sulawesi Ophiolite Belt in the eastern arm, and (4) the Banggai-Sula and Tukang Besi continental fragments (Fig.1). Each tectonic province has occurrences of pre-Tertiary rocks containing metamorphic and mafic-ultramafic suites. The mafic-ultramafic sequences have been variously interpreted as members of ophiolites from different tectonic settings (Fig. 2). Based on this widely distributed, large potential of Sc resources is expected in Indonesia because of large Ni-resources. It is reported that Sc will be enriched in limonite or saprolite since Sc is relatively mobile (soluble) in a limonite zone although it is an immobile element. In acidic limonite zone Sc³⁺ is not likely to adsorbed on hematite and goethite. In neutral-alkaline saprolite zone Sc³⁺ may be partially adsorbed in saprolite zone (if Sc³⁺ is dissolved in solution). Sc³⁺ is mostly incorporated in mineral structures in Ni laterite.

2. Rare earth elements

The granitic rocks are widely distributed in Sulawesi Island in the central part of Indonesian Archipelago (Sukamto, 1979; Maulana, 2013). They occupy the western part to the northern part of the island, encompassing for more than 400 km. The island is situated in the equatorial line and hence is located in tropical climate, causing the surface of the rocks is susceptible to weathering and alteration process. It has been reported that REE are mobile and tend to be enriched during weathering of granitic rocks in some sub tropic areas (Bao and Zhao, 2008). In addition, enrichments of REE in weathered granitic crusts from tropic areas were also reported (Sanematsu et al. 2009; Sanematsu et al. 2011). Generally, the granitic rocks in Sulawesi are heavily weathered for example Polewali and Mamasa area (Fig. 3). The enrichment of REE in the weathered granitic rocks can be found in two types, namely; placer deposit and ion-adsorption type deposit (Fig. 4). The typical of the granitic rocks which enriched in REE is predominantly I-type granitic rocks. REE are adsorbed on clay (e.g. kaolinite, halloysite) and can be extracted by ion-exchangeable electrolyte solution (Fig. 5).

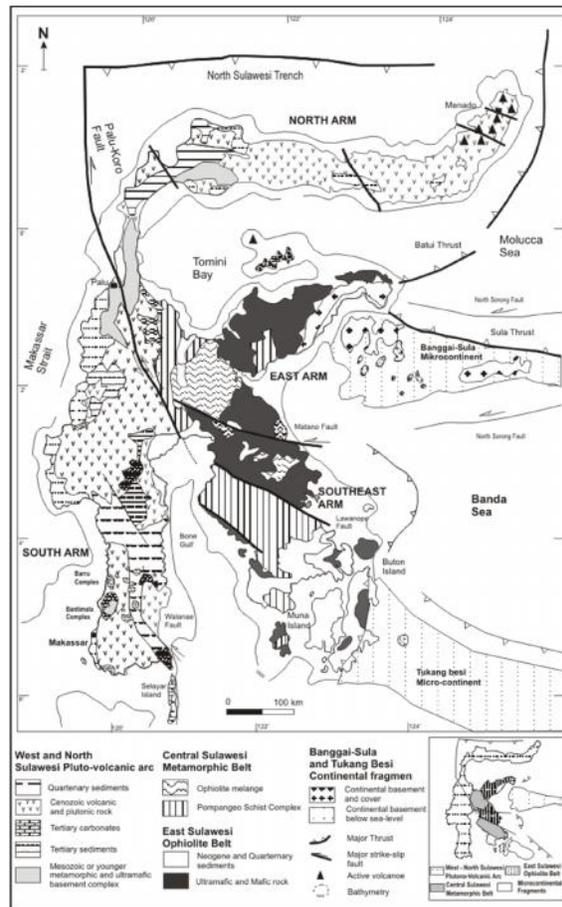


Fig. 1. Geological map and tectonic setting of Sulawesi Island (modified after Kadarusman et al., 2004; Maulana, 2009).

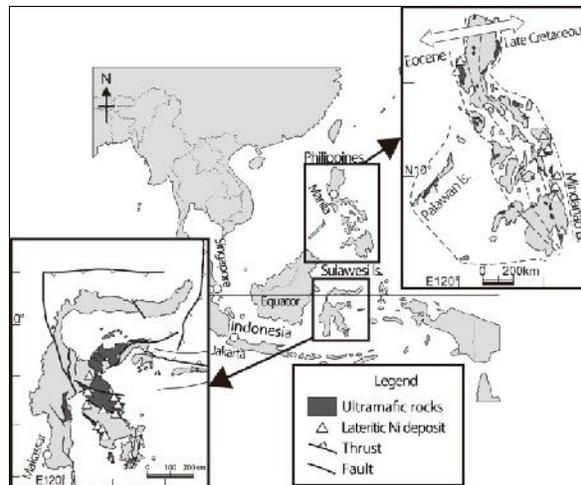


Fig. 2. Ultramafic rocks and lateritic Ni deposit distribution in Sulawesi Island. Inset figure show ultramafic and lateritic Ni deposit distribution in Philippines which have been exploited for Sc.

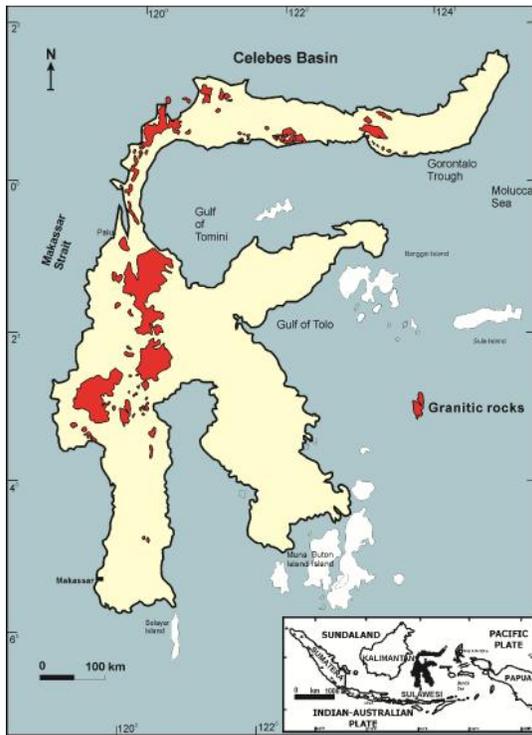


Fig. 3 Distribution of granitic rocks in Sulawesi

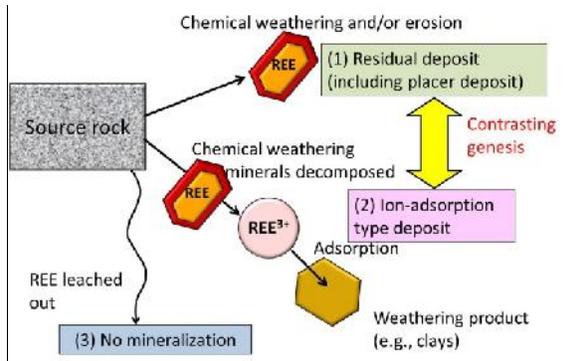


Fig. 4 Mechanism of REE enrichment in residual deposit and ion-adsorption deposit

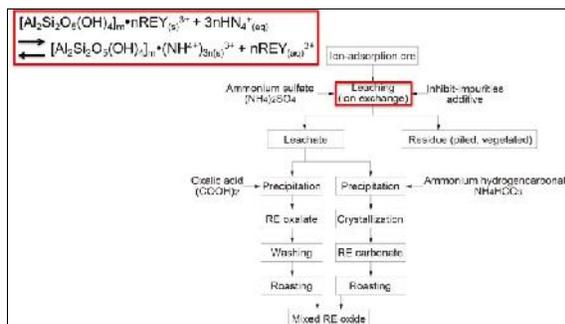


Fig. 5. Simplified flowsheet of REE extraction using ammonium sulphate solution (Chi & Tian, 2007)

Conclusion

1. Sc-bearing laterite Ni deposit in Sulawesi could be a dominant source of Sc resources in near future. Sc is likely to substitute Fe³⁺ site of mafic minerals (pyroxene, amphibole, etc) but further studied are required. Metallurgical process has an important role to extract Sc economically from Ni laterite.
2. REE resources in Sulawesi can be extracted from ion-adsorption type deposit from heavily weathered I-type granitic rocks in Sulawesi. REE-sourced minerals are predominantly allanite, titanite and REE fluorocarbonate. Depletion of Ce (negative Ce-anomaly) in weathered granite is a good indicator of ion-adsorption ores.
3. Further detail study on the occurrence of critical metal (Scandium) and rare earth element therefore should be conducted intensively in order to maximize the potential of these materials for better development.

Acknowledgments

We would like to express our sincere gratitude to MEXT Scholarship for financial support. PT Vale Indonesia is greatly acknowledged for their facility and permit.

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