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# Study on the Critical Metal and Rare Earth Element Occurrences in Sulawesi

A. Maulana[1], K. Sanematsu[2]

[1]Geology Department, Hasanuddin University, Makassar
[2]Japan Advanced Institute of Science and Technology, Japan
Email: *adi-maulana@unhas.ac.id*

**ABSTRACT**

As the development of modern-high technology application is growing, demands of the constant supply of Scandium (Sc) and rare earth elements (REE) as a new green source of energy is increasing. Meanwhile, source of these elements are limited hence new source of these minerals have to be found. Nowadays, 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. Exploration on critical metals and rare earth element in Indonesia is still scarce due to lacking of skillful human resource who understand about the occurrences and distribution of these elements. Based on the most update investigation, critical metal particularly Scandium can be found in 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. Meanwhile, rare earth element found in granitic rocks particularly in zircon, monazite and xenotime. It has been reported that rare earth ore were extracted from heavily weathered granitic rocks. Sulawesi Island is one of the island where lateritic deposit from heavily weathered ultramafic can be found. The lateritic soil can be potential source of scandium. Meanwhile, granitic rocks cover almost 20% of the island which also potential source of rare earth element. These suggest that Sulawesi Island has a big potential and challenge for critical metal and rare earth element exploration. This manuscript reports the exploration potential and challenge of critical metal and rare earth element in Sulawesi based on geological data.

*Keywords: critical metal, rare earth element, exploration, Sulawesi*

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## 1. INTRODUCTION

Nowadays, 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. Meanwhile, 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 the potential distribution of Sc and REE in Indonesia.

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, pyroxinite 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 $Fe^{3+}$, $Al^{3+}$, $Ti^{3+}$ and other sites in laterites. The

Peridotite as a host of Sc-bearing mineral is largely distributed in Sulawesi island. 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 [1,2]. This rock is widely distributed in Sulawesi Island, covering almost 20% of the island. However, report on the occurrence of rare earth elements from this rock is still lacking despite its important economic value.

This manuscript will report the preliminary investigation result of scandium and rare earth elements occurrences in Sulawesi and its exploration potential and challenge.

*A. 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 $Ni^{2+}$ is generally incorporated into mafic minerals in magma and that they are easily altered by soil or ground water. The previous studies indicate that $Sc^{3+}$ 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. It is very likely that low-grade Ni laterite maybe rich in Sc.

*B. Rare earth element*

Rare earth elements mineralization occur in some deposit types; e.g. carbonatite rock formation, granitic rocks [1], manganese deposit hydrothermal iron-ore deposit, placer deposit, lateritic soil, ion adsorption weathering crust [1] and uranium deposit. One of the most promising sources of these elements is granitic rocks as reported by previous studies [1,2]. 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. In 1992, REEs from these deposits comprised 14% of Chinese production, and this source has had a strong impact on yttrium supplies since 1988. The deposits reportedly form weathering crusts over granite. 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. Ore from Longnan has an HREE-dominated distribution pattern very similar to that of xenotime, whereas ore from Xunwu is relatively enriched in lanthanum [3]. 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. The deposits are considered to be laterites and show similarities to a number of other lateritic deposits formed over alkaline igneous rocks and carbonatite.

### *C. 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 [3].

## 2. 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

### *A. Mineralizing characteristic of ionic type REE deposits*

In fact, 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 usuallu about 5 – 10 meters and the thickest is about 20 meters; (d) semi-weathered layer which is 3 – 5 m thick; (e) bedrock granitoids.

1) Mineral compositions of ionic type REE deposits
2) 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 $Al_2SiO_5$ $(OH_4)$. 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 $(Na, Ca)_{0.33}$ $(Al, Mg)_2Si_4O_{10}(OH)2.nH2O$, gibbsite $Al(OH)_3$, hydrobiotite which is mixture of biotite and vermiculite $K(Mg,Fe_3)$ $(Al,Fe)SiO_{10}(OH, F_2)$ and $(Mg,FeAl)_3(Al,Si)_4O_{10}(OH).4H_2O$.

### *B. Primary RE minerals*

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

## 3. Exploration potential and challenge in Sulawesi

### *A. Scandium*

Sulawesi Island is located in the central part of the Indonesian archipelago, which consists of four tectonic provinces [4]: (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. Each tectonic province has occurrences of pre-Tertiary rocks containing metamorphic and mafic-ultramafic suites. The mafic-ultramafic

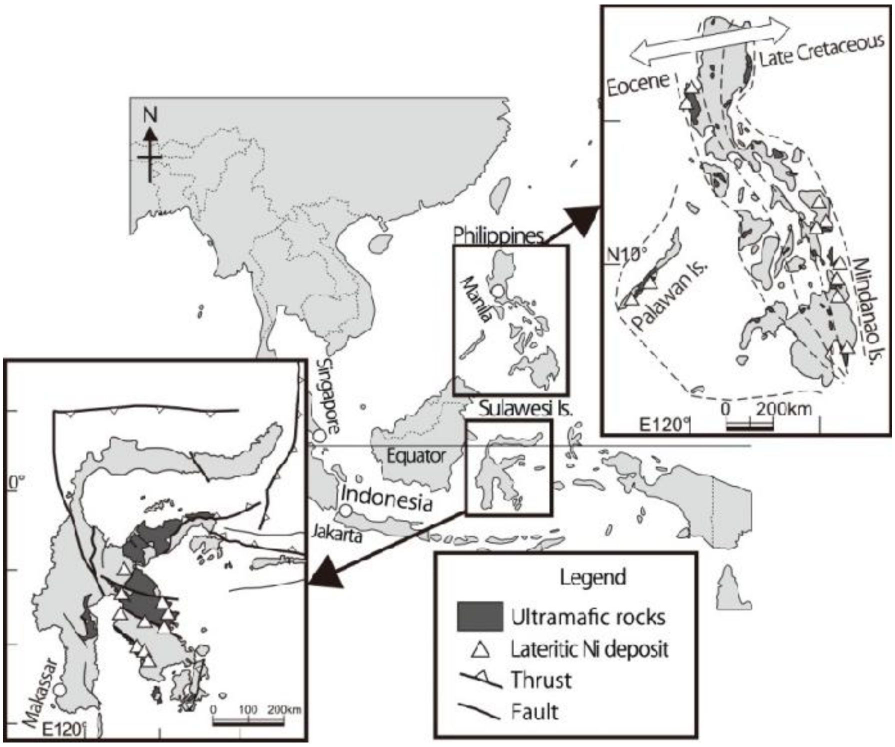


Fig. 1. Ultramafic rocks and lateritic Ni deposit distribution in Sulawesi Island. Inset figure show ultramafic and lateritic Ni deposit distribution in Philippines which have been exploited for Sc.

sequences have been variously interpreted as members of ophiolites from different tectonic settings (Fig. 1). 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 $Sc^{3+}$ is not likely to adsorbed on hematite and goethite. In neutral-alkaline saprolite zone Sc3+ may be partially adsorbed in saprolite zone (if $Sc^{3+}$ is dissolved in solution). $Sc^{3+}$ is mostly incorporated in mineral structures in Ni laterite.

*B. Rare earth elements*

The granitic rocks are widely distributed in Sulawesi Island in the central part of Indonesian Archipelago [5,6]. They occupy the western part to the northern part of the island, encompassing for more than 400 km (Fig.2). 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 [1,3]. In addition, enrichments of REE in weathered granitic crusts from tropic areas were also reported [7,8].

Generally, the granitic rocks in Sulawesi are heavily weathered for example Polewali and Mamasa area. The enrichment of REE in the weathered granitic rocks can be found in two types, namely; placer deposit and ion-adsoprtion type deposit (Fig. 2). 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. 3).

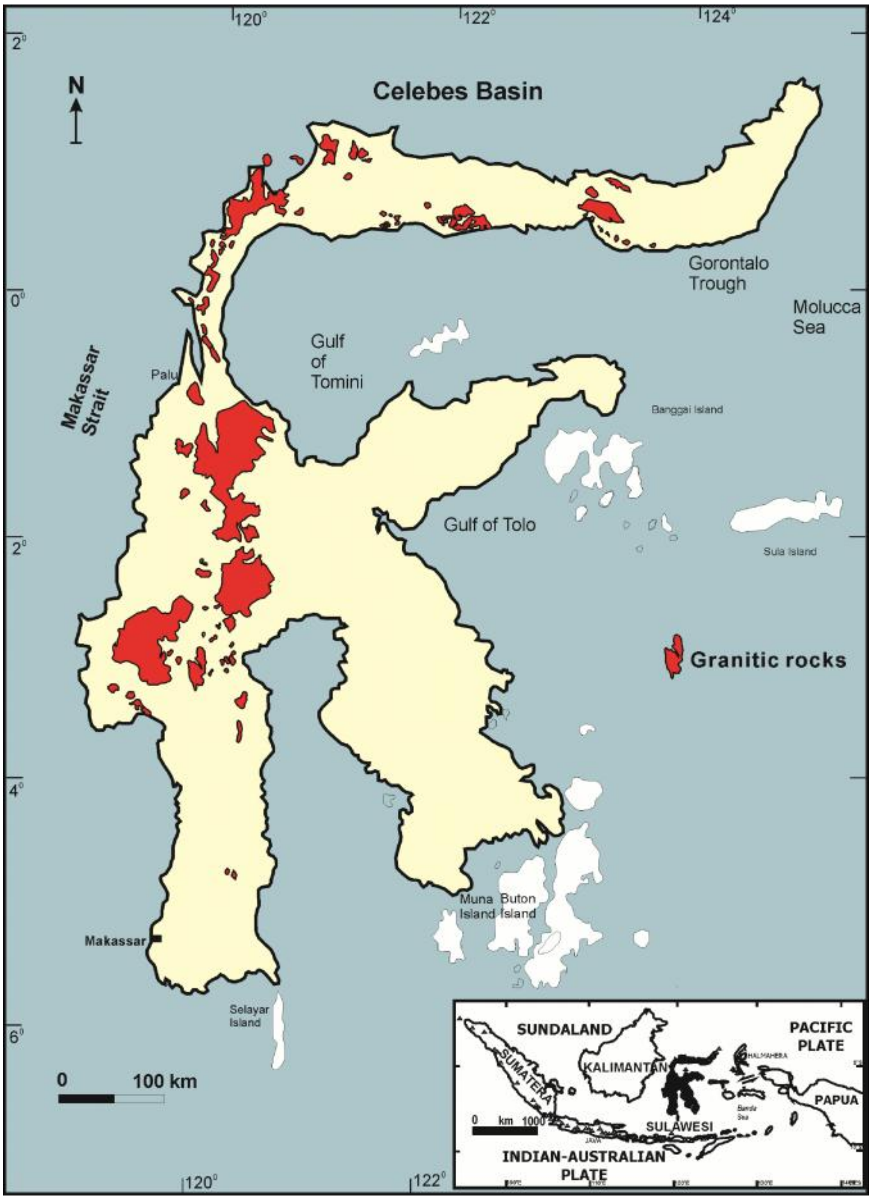


Fig. 2 Distribution of granitic rocks in Sulawesi Island [6].

## 4. CONSLUSION

This manuscript shows the future potential of critical metal and rare earth element exploration as well as challenge in Sulawesi Island. Sc-bearing laterite Ni deposit 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. 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 flourocarbonate. Depletion of Ce (negative Ce-anomaly) in weathered granite is a good indicator of ion-adsorption ores. 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.

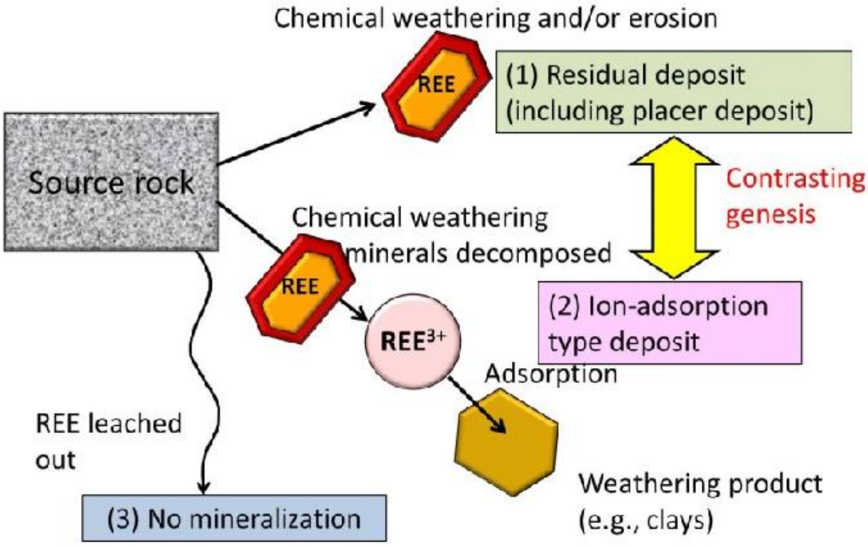


Fig. 3 Mechanism of REE enrichment in residual deposit and ion-adsorption deposit

## 5. Acknowledgments

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