An Overview on the Possibility of Scandium and REE Occurrence in Sulawesi, Indonesia

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Abstract - The development in modern-high technology application is growing rapidly, resulting in the 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 critical metals is an important metal for electrolyte of solid oxide fuel cells and other advance technology. In addition, REE are the important elements in the use of permanent magnets and rechargeable batteries. This manuscript reports an overview on the possibility of scandium and rare earth element occurrences in Sulawesi. Sc is concentrated in limonite layers in Soruko ultramafic rocks as a result of Fe³⁺ site substitution of mafic minerals (pyroxene, amphibole, etc.) during a laterization process. REE are enriched in association with clay minerals in B horizon from heavily weathered granitic rocks in Palu and Masamba, suggesting the possibility of ion-adsorption style mineralization. The lateritic soil of the ultramafic rocks and the weathered crusts of the granitic rocks in Sulawesi could be the potential sources of scandium and rare earth elements, respectively.

Keywords: scandium, rare earth element, Sulawesi, Indonesia

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Introduction

Rare metals, including scandium (Sc) and rare earth elements (REE) have become a critical issue due to their dramatic increase in industrial use as well as their rarity. Sc is an important metal for electrolyte of solid oxide fuel cells, and the demand is likely to increase in the near future. However, Sc is not found for free in nature, but it is combined with other limited rare minerals. In addition, REE are the essential elements in the use of permanent magnets, rechargeable batteries, and some modern technology equipments. Nevertheless, REE are heavily dependent on some weathered crust deposits in China (ex. Bayan Obo Deposit and highly weathered granitic rocks from southern China) (Ishihara et al., 2008). These conditions have led to the growing concern that the world may soon face a shortage of Sc and REE resources. Therefore, other sources of Sc and REE are expected to be developed in order to balance the 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.
The primary source of scandium is derived from by-product of uranium mill tailings with world productions amount to only 50 kg per year. There is no estimate of how much the available potential is (Duyvesteyn and Putnam, 2014). As Sc is a compatible element, mafic and ultramafic rocks generally have higher Sc contents. Sc is incorporated into pyroxene (or amphibole), but is rarely contained in olivine (Leeman and Scheidegger, 1977). In the process of chemical weathering of ultramafic rocks known as laterization, 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⁺, Ti⁴⁺ and other sites in laterites (Onuma et al., 1968; Sanematsu et al., 2014; Maulana et al., 2015).

It has been reported that REE are mobile and tend to be enriched during the weathering of granitic rocks in some subtropical areas (Bao and Zhao, 2008). Enrichments of REE in weathered granitic crusts from tropic areas were also reported (Sanematsu et al., 2009; Sanematsu et al., 2013). The enrichments of REE in the weathered granitic rocks can be found in two types, namely; placer deposit and ion-adsorption type deposit. The typical 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 (Imai et al., 2013; Sanematsu et al., 2013).

Peridotite as a host of Sc-bearing mineral and granitic rocks as sources for REE are largely distributed in Sulawesi as shown in Figures 1 and 2. However, despite their vast distribution, there are no detailed studies on Sc and REE occurrences in this island. The most recent study was conducted by Maulana et al. (2014) who reported the geochemical characteristic of REE in a weathered crust from granitic rocks in Sulawesi.

This study reports an overview on the possibility of Sc and REE occurrences from ultramafic and granitic rocks weathering profile, respectively in Sulawesi. The result will be used for discussion on their enrichment process in the two types of rocks.

**Material and Methods**

Two campaign field works have been conducted to collect some samples. Some lateritic profiles from weathered ultramafic rocks in Soroko area (Petea and West Block) were chosen to determine the occurrences of Sc. REE study was concentrated in weathered granitic rocks from Palu and Masamba areas.

The weathered ultramafic and granitic rock samples were analyzed for concentration of major elements using an X-ray fluorescence spectrometer (XRF) RIGAKU RINT-300 in Advance Institute of Science and Technology (AIST) Laboratory in Tsukuba and Department of Earth Resource Engineering, Kyushu University. Rare earth and trace elements including scandium composition for both sample groups were determined by the ICP-MS following lithium metaborate/tetraborate fusion and nitric acid total digestion at ALS Mineral, North Vancouver, Canada.

**Result**

**Geochemistry of Sc in Weathering Profile of Ultramafic Rocks**

Most of ultramafic sequences in Soroko area have been weathered intensely and produced a lateritic profile (Achmad, 2006). The profile mainly consists of bedrock, saprolite, limonite, and top soil layer showing various ranges of thickness (Figure 3). Results of chemical analyses for weathering profile of ultramafic rocks from Petea and West Block are described in Figure 4. Bedrocks in these two areas are classified as harzburgite in composition. The bedrock in Petea profile contains of 40.8 wt% SiO₂, 34.8 wt% of MgO, 8.7 wt% Fe₂O₃, 0.2 wt% Ni, and 9.8 ppm Sc. In relation to this, the weathering profile shows a decreasing content of SiO₂ and MgO, and an increasing trend of Fe₂O₃ and Sc.
from bedrock to limonite layer. $\text{SiO}_2/\text{MgO}$ ratio and Sc show a slightly increasing trend from bedrock to soft saprolite, but significantly enriched in yellow limonite layer. Overall, West Block weathering profiles show a somewhat similar pattern to the Petea profile. $\text{SiO}_2$ and MgO are significantly decreasing, whereas $\text{Fe}_2\text{O}_3$, Sc, and $\text{SiO}_2/\text{MgO}$ ratio are increasing.
Figure 2. Map showing granitic rocks, ultramafic rocks, and lateritic Ni deposit distribution in Sulawesi Island. Inset figure shows ultramafic and lateritic Ni deposit distribution in the Philippines which have been exploited for Sc (Granitic rocks distribution is from Maulana, 2013; ultramafic rocks distribution from Kadarusman et al., 2004; Ni deposit in the Philippines is from Yumul, 2007).

Figure 3. Weathering profile of (a) lateritic deposit from ultramafic rock in Soronko area and (b) granitic rocks from Palu area.

toward the upper part of the weathering profile. These two variations suggest the enrichment of Sc was concentrated in the limonite horizon as shown by the profile pattern.

Geochemistry of REE in Weathered Granitic Rocks

Weathered granitic rocks in Palu and Mamasa consist of bed rock, horizon B. Concentration
and variation of REE in the weathered granitic crusts in the studied area are summarized in Figure 5. Generally, the weathered crusts show a higher concentration of total REE and REE + Y compared to their parent rocks as reported by Maulana et al. (2014). This result indicates that weathered crusts were enriched in REE, consistent with enrichment of REE in weathered granitic crusts reported from many areas (Ishihara et al., 2008; Imai et al., 2013). However, the Palu weathered crust only shows a small enrichment of REE compared to the Mamasa weathered crust.

The total REE content of the Mamasa weathered crusts ranges from 58 to 552 ppm (322 ppm on average), whereas those of fresh (parent) rocks range from 20 to 356 ppm with the average of 198 ppm (sample MA-38 and MA-43B which have low SiO₂ content were not used in the average calculation). The ∑LREE content of the weathered samples ranges from 46 to 488 ppm, whereas the total of HREE content ranges from 10 to 64 ppm. La and Ce are the most abundant elements in all samples.

In contrast, the ∑REE content in Palu weathered crusts only shows a very small enrichment (approximately 20%) compared to their parent rocks. The ∑REE content in Palu weathered crusts ranges from 124 to 314 ppm (223 ppm in average), whereas the ∑REE content in the parent rocks ranges from 196 to 251 (200 ppm in average). The total ∑REE + Y content in the weathered crusts ranges from 220 to 337 ppm and 198 to 267 ppm
in the parent rocks. The enrichment of REE occurred mainly in B-2 horizon, where the total REE content is up to 314 ppm (REE + Y = 337 ppm).

**DISCUSSION**

**Scandium**

Sc occurrence in Sulawesi was firstly reported by Kadarusman et al. (2004) and Maulana et al. (2015) from bulk rock composition of ultramafic rocks. It is reported that Sc content is abundant in pyroxenite from Bantimala Complex, South Sulawesi (Maulana et al., 2015). Sulawesi Island is located in the central part of the Indonesian Archipelago, which consists of four tectonic provinces (Kadarusman et al., 2004; Maulana, 2009; Maulana et al., 2015): (1) the West and North Sulawesi Pluton-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 (Figure 1). Each tectonic province has occurrences of Mesozoic rocks containing metamorphic and mafic-ultramafic suites. The mafic-ultramafic sequences have been variously interpreted as members of ophiolites from different tectonic settings (Figure 2).

Whole-rock geochemical data of the laterites from Soroako ultramafic rocks suggest that Sc is likely to exist in Fe oxides and pyroxene-rich bedrock (harzburgite in composition). Notably, Sc tends to be enriched in limonite layers. Sc is unlikely to be adsorbed on minerals and amorphous materials in the laterites. Sc is more distributed in pyroxene-rich bedrock than in olivine since coefficient value of scandium is hosted in orthopyroxene and clinopyroxene as listed in Table 1. The enrichment of Sc will mainly be concentrated in the weathering product of pyroxene-rich bedrock (peridotite and pyroxenite), particularly in limonite layer with low to medium Ni-content. Based on this, large potential of Sc resources is expected in Soroako because of large weathered pyroxene-rich ultramafic rocks as a source of nickel (Ni)-laterite deposit.

**Rare earth element**

The granitic rocks are widely distributed in Sulawesi Island in the central part of the Indonesian Archipelago (Sukamto, 1975; Maulana, 2013) (Figures 1 and 2). They occupy the western part to the northern part of the island, encompassing more than 400 km. The island is situated in the equatorial line, and hence is located in the tropical climate causing the surface of the rocks is susceptible to weathering and alteration process.

REE content has recently been reported from granitic rocks in Sulawesi (Maulana et al., 2014). Generally, the granitic rocks in Sulawesi are heavily weathered, for example in Polewali and Mamasa areas (Maulana et al., 2014). The weathering profile shows a thickness of 2 to 5 meters consisting of generally two horizons, A and B (Figure 3b). REE content in bedrock of
granitic rocks in Sulawesi ranges from 110 - 250 ppm and enriched in weathered profile by 1.5 to 2 times (Maulana et al., 2014). This enrichment suggests the possibility of ion-adsorption type deposit of REE in weathered granitic rocks from Sulawesi. Maulana et al. (2014) reported the occurrence of clay mineral such as montmorillonite and kaolinite associated with REE enrichment in Sulawesi. The REE occurrence in Sulawesi is further supported by the I-type granitic rocks domination (Maulana et al., 2016).

The existence of Sc and REE at these concentration levels in weathered ultramafic and granitic rocks has significant implications in the study of these elements. This is of economic interest as Sc and REE elements tend to concentrate in the weathering profile of ultramafic and granitic rocks, and also because Sc is notably fixed in Fe rich mineral, and REE is hosted in weathering-product mineral (clay mineral). Thus, it shows that both Fe rich mineral (pyroxene) may be a significant host for Sc in the weathered ultramafic rocks, and clay mineral may adsorb REE in the weathering process of granitic rocks.

From the economic point of view, the high levels and uniformity of distribution suggested by our study indicate that the limonite layers in the weathering profile of ultramafic rocks and B horizon in weathered crust of granitic rocks may be a viable source of scandium and REE, respectively.

in the near future. Sc is likely to substitute Fe3+ site of mafic minerals in the weathering product of pyroxene-rich ultramafic bedrocks, but further studies are required.

2. REE resources in Sulawesi can be extracted from ion-adsorption type deposit of heavily weathered I-type granitic rocks in Sulawesi.

3. As weathered ultramafic and granitic rocks in Sulawesi are widely distributed, it is expected that Sc and REE can economically be extracted in the future.

4. Further detailed studies on the occurrence of these critical metals (Sc and REE) should therefore be conducted intensively in order to maximize the potential of these materials for the better development.

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