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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 Soroako ultramafic rocks as a result of Fe^{3+} 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 Fe^{3+}, Al^{3+}, Ti^{3+} 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-adsoprtion 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 Soroako 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 Soroako 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% SiO_2, 34.8 wt% of MgO, 8.7 wt% Fe_2O_3, 0.2 wt% Ni, and 9.8 ppm Sc. In relation to this, the weathering profile shows a decreasing content of SiO_2 and MgO, and an increasing trend of Fe_2O_3 and Sc

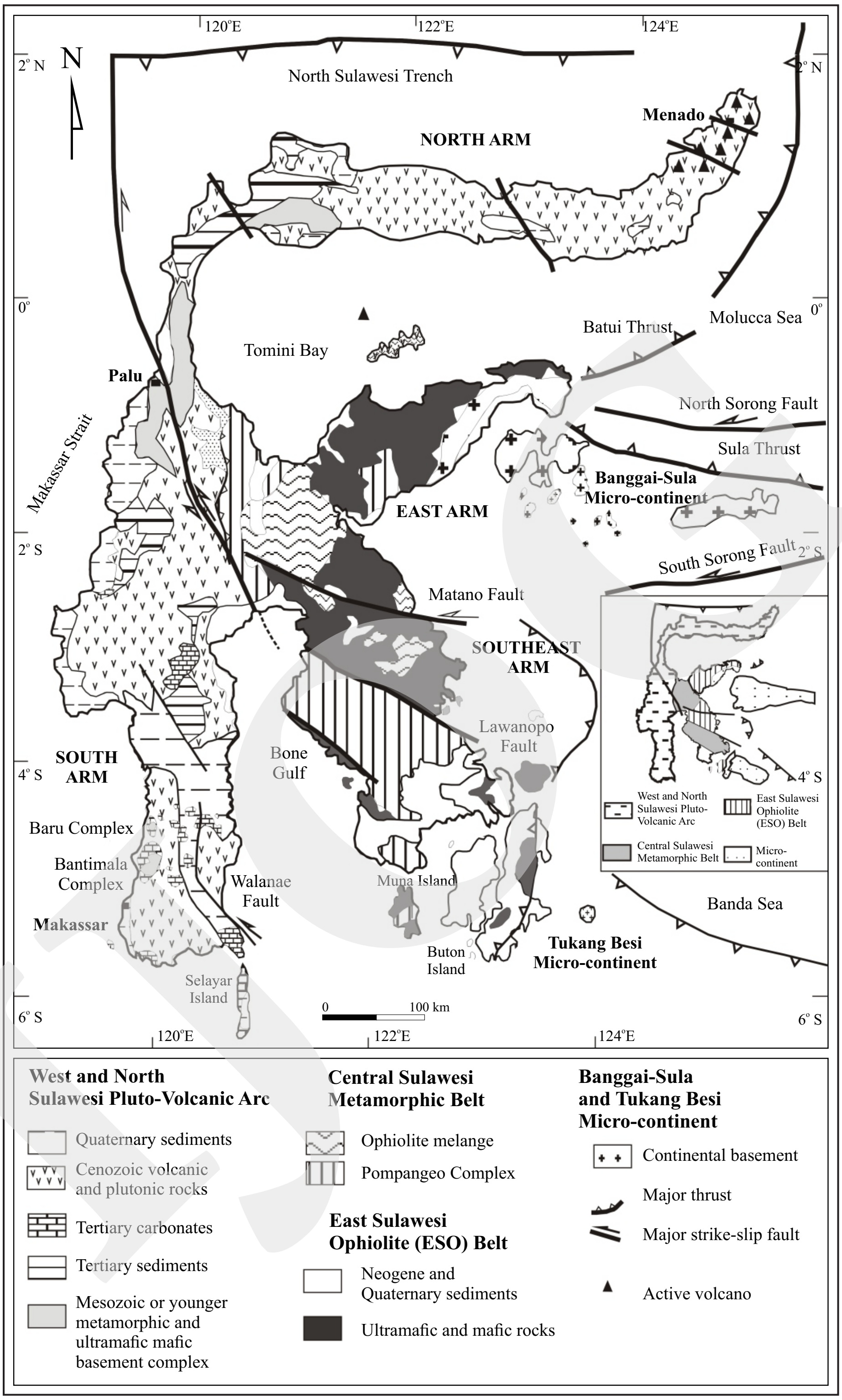

Figure 1. Geological map and tectonic setting of Sulawesi Island (modified after Kadarusman *et al*., 2004; Maulana, 2009).

from bedrock to limonite layer. SiO_2/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. SiO_2 and MgO are significantly decreasing, whereas Fe_2O_3, Sc, and SiO_2/MgO ratio are increasing

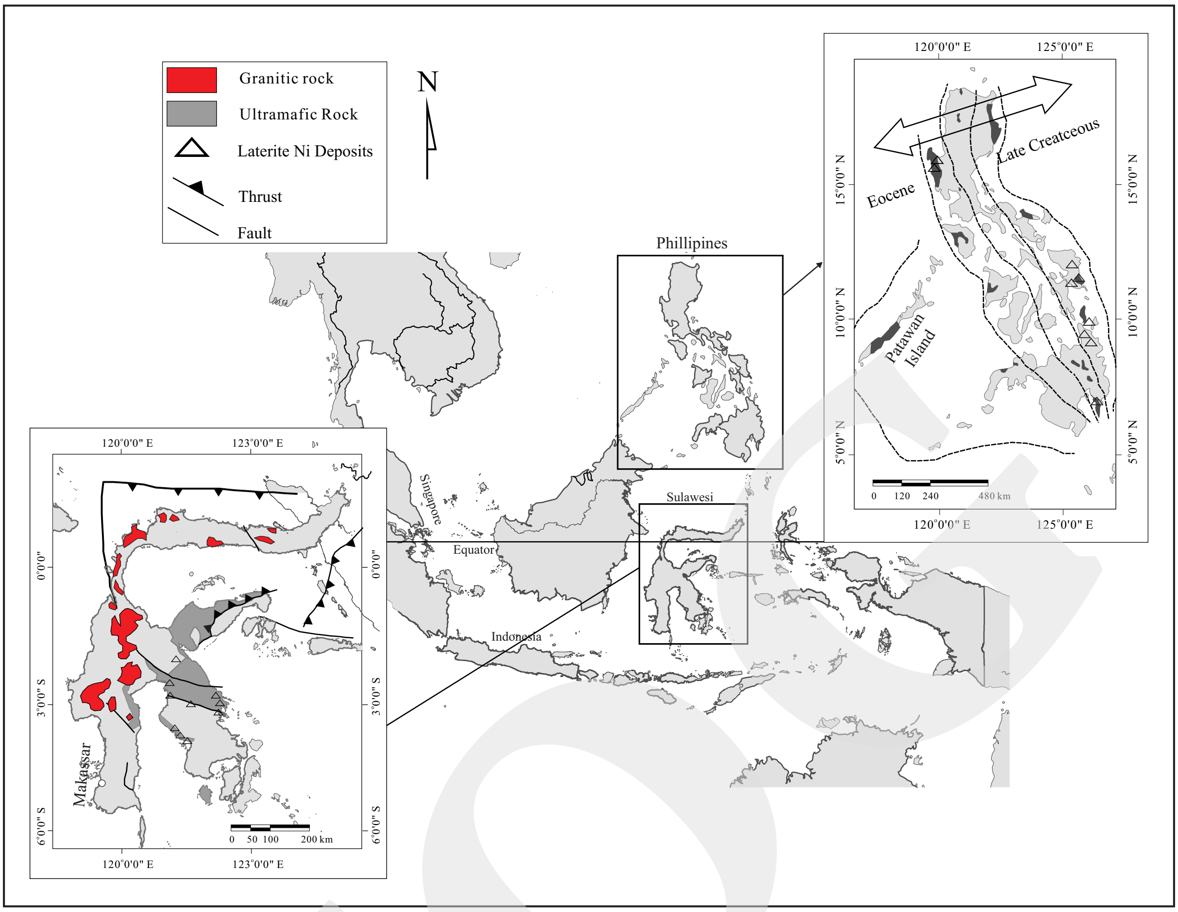

Figure 2. Map showing granitic rocks, ultramafic rocks, and lateritic Ni deposit distribution in Sulawesi Island. Inset figure show ultramafic and lateritic Ni deposit distribution in the Philippines which have been exploited for Sc (Granitic rocks distribution is from Maulana, 2013; ultramafic rocks distribution from Kadarusman *et al*., 2004; Ni deposit in the Phillippines is from Yumul, 2007).

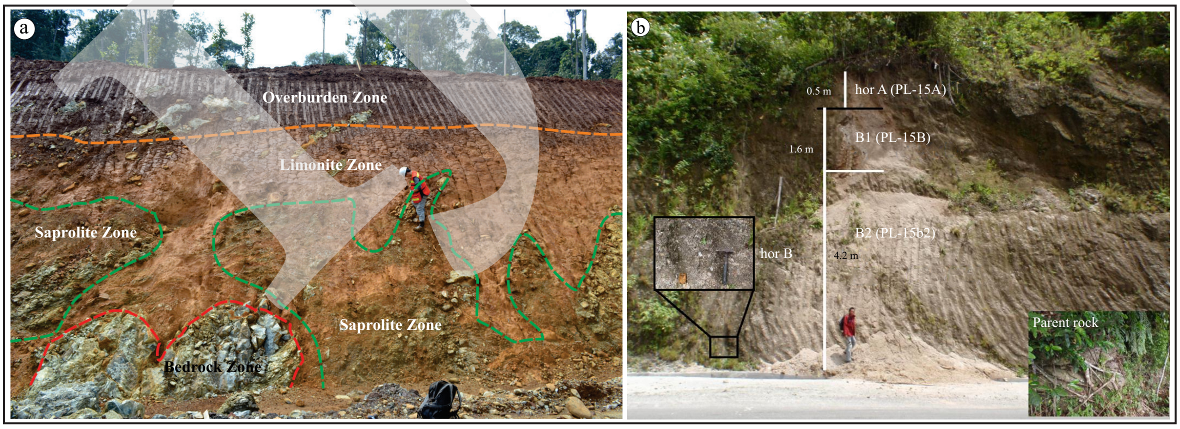

Figure 3. Weathering profile of (a) lateritic deposit from ultramafic rock in Soroako area and (b) granitic rocks from Palu area.

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

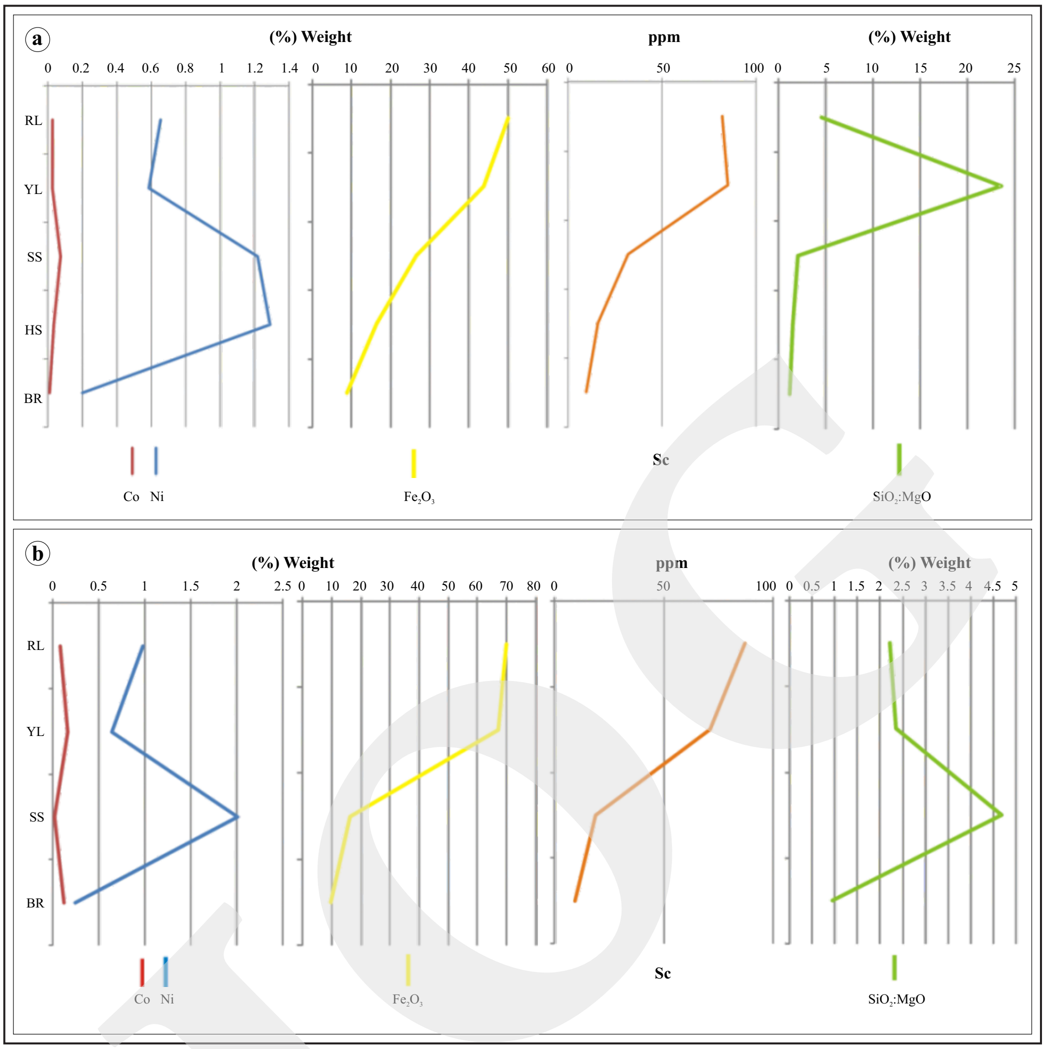

Figure 4. Diagram showing vertical distribution of some elements in: (a). Petea; (b).West Block.

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 SiO_2 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

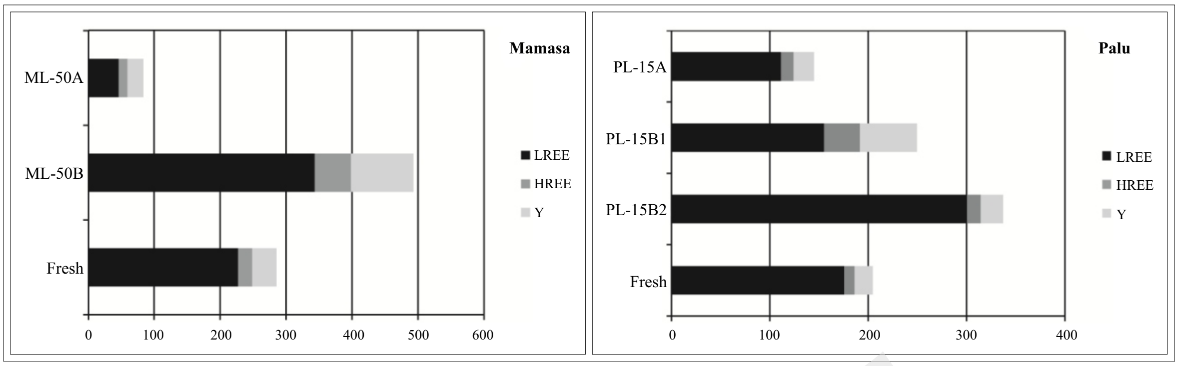

Figure 5. REE composition of weathered granitic rocks from: (a). Mamasa, and (b).Palu.

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 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 (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 proxene-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

Table 1. Partition Coefficient Value of Some Minerals (Sanematsu *et al*., 2013)

Partition coefficient	Minerals	Rock type	Method
0.14 - 0.22	Olivine	Basalt	Phenocryst and matrix
1.23 - 2.92	Othopyroxene	Basalt	Phenocryst and matrix
2.5 - 3.5	Clinopyroxene	Basalt and andesite	Phenocryst and matrix
2.18	Amphibole	Basalt	Phenocryst and matrix
0.008	Plagioclase	Basalt	Experiment
1.96	Magnetite	Basalt, andesite, and dacite	Phenocryst and matrix
1.8	Limenite	Basalt	Experiment

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 suggets 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 montmorilonite 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.

Conclusion

1. Sc-bearing laterite Ni deposit in Sulawesi could be a dominant source of Sc resources 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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References

Achmad, W., 2006. Laterite: fundamental of chemistry, mineralogy, weathering process and laterite formation. Soroako, South Sulawesi. *PT International Nickel Indonesia*.

Bao, Z. and Zhao, Z., 2008. Geochemistry of mineralization with exchangeable REY in the weathering crusts of granitic rocks in South China. *Ore Geology Review*, 33, p.519-535. DOI: 10.1016/j.oregeorev.2007.03.005

Duyvesteyn, W.P.C. and Putnam, G., 2014. Scandium: A review of the element, its characteristic, and current and emerging commercial application. *EMC Metal Corporation White Paper*, p.12.

Imai, A., Yonezu, K., Sanematsu, K., Ikuno, T., Ishida, S., Watanabe, K., Pisutha-Arnond, V., Nakapadungrat, S., and Boosayasak, J., 2013. Rare earth element in hydrothermally altered granitic rocks in the Ranong and Takua Tin-Field, Southern Thailand. *Resource Geology*, 63 (1), p.98. DOI: 10.1111/j.1751-3928.2012.00212.x

Ishihara, S., Hua, R., Hoshino, M., and Murakami, H., 2008. REE abundance and REE minerals in Granitic Rocks in the Nanling Range, Jiangxi Province, Southern China, and Generation of the REE-rich Weathered Crusts Deposits. *Resource Geology*, 58 (4), p.373-401. DOI: 10.1111/j.1751-3928.2008.00070.x

Kadarusman, A., Miyashita, S., Maruyama, S., Parkinson, C.D., and Ishikawa, A., 2004. Petrology, geochemistry and paleogeographic reconstruction of the East Sulawesi Ophiolite, Indonesia. *Tectonophysics*, 392, p.55-83. DOI: 10.1016/j.tecto.2004.04.008

Leeman, W.P. and Scheidegger, K.F., 1977. Olivine/liquid distribution coefficient and a test for crystal-liquid equilibrium. *Earth and Planetary Science Letter*, 35, p.247-257. DOI: 10.1016/0012-821X(77)90128-5

Maulana, A., 2009. *Petrology, Geochemistry and Metamorphic Evolution of the south Sulawesi Basement Rocks Complexes, Indonesia. M.Phil Thesis*. The Australian National University.

Maulana, A., 2013. *A Petrochemical study of granitic rocks from Sulawesi Island, Indonesia. Doctoral dissertation*. Kyushu University, Fukuoka.

Maulana, A., Christy, A.G., and Ellis, D.J., 2015. Petrology, geochemistry and tectonic significance of serpentinized ultramafic rocks from the South Arm of Sulawesi. *Chemie der Erde*, 75(1), p.73-88. DOI: 10.1016/j.chemer.2014.09.003

Maulana, A., Imai, A., Van Leeuwen, T., Watanabe, K., Yonezu, K, Nakano, T., Boyce, A., Page, L., and Schersten, A., 2016. Origin and geodynamic setting of Late Cenozoic granitoid in Sulawesi, Indonesia. *Journal of Asian Earth Sciences*, 124, p.102-125. DOI: 10.1016/j.jseaes.2016.04.018

Maulana, A., Yonezu, K., and Watanabe, K., 2014. Geochemistry of rare earth elements (REE) in the weathered crusts from the granitic rocks in Sulawesi Island, Indonesia. *Journal of Earth Science*, 25 (3), p.460-472. DOI: 10.1007/s12583-014-0449-z

Onuma, N., Higuchi, H., Wakita, H., and Nagasawa, H., 1968. Trace element partitionbetween two pyroxenes and the host lava. *Earth and Planetary Science Letters*, 5, p.47-51. DOI: 10.1016/S0012-821X(68)80010-X

Sanematsu, K., Arcilla, C., Maulana, A., and Zhaw, K., 2014. Future resource potential of Scandium in nickle laterite. *Abstract of Asian Oceania Geology Symposium*, Beijing, China.

Sanematsu, K., Kon, Y., Imai, A., Watanabe, K., and Watanabe, Y., 2013. Geochemical and mineralogical characteristic of ion-adsorption type REE mineralization in Phuket, Thailand. *Mineralium Deposita*, 48, p.437-451. DOI: 10.1007/s00126-011-0380-5

Sanematsu, K., Murakami, H., Watanabe, Y., Duangsurigna S., and Vilayhack, S., 2009. Enrichment of rare earth element in granitic rocks and their weathered crusts in central and southern Laos. *Bulletin of the Geological Survey of Japan*, 60 (11/12), p.527-558. DOI: 10.9795/bullgsj.60.527

Sukamto, R., 1975. *Geological Map of Ujung Pandang Sheet, scale 1:1.000.000*. Geological Survey of Indonesia, Bandung.

Yumul, Jr., G.P., 2007. Westward younging disposition of Philippine ophiolite and its implication for arc evolution. *Island Arc*, 16, p.306-317. DOI: 10.1111/j.1440-1738.2007.00573.x