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Review on Granitic Rocks in Sumatra: Intrusion Process, Classification, Mineralization, and Potential Uses

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ABSTRACT

Granitic rocks are widely distributed in Sumatra and surrounding areas. These granitoids are classified into several granite provinces of Southeast Asia with different intrusion processes and specific characteristics. This paper aims to review the intrusion of granitic rocks in Sumatra and describe the opportunities associated with it. Granite rocks are used to manufacture cultural heritage, works of art, and ornaments because of their weathering resistance, color diversity, and hardness characters. S-type granite intrusion in Sumatra might be associated with tin mineralization while silver-gold with the I-type. Theoretically, granite contains more REE than other igneous rocks. Mining and extraction difficulties complicate the direct REE exploitation from fresh granite. A-type granite relatively contains more REE than the other types, but this type of granite is not correlated with certain provinces. Indonesia has a tropical climate which is prone to weathering. Therefore, it is possible for REE and/or bauxite enrichments in the granite weathering horizon. Granite is assumed to be a potential source of uranium and thorium, especially for the S-type, because it is formed through the compression of sediments that can absorb these radioactive elements from the continental crust.

Keywords: Sumatra, granite, classification, mineralization

INTRODUCTION

Southeast Asia is built of several continental plates, namely West Sumatra, Sibumasu, East Malaya, Indochina, Southwest Borneo, West Burma, and South China (Figure 1). The plates originate from Gondwanaland and their evolution is related to the opening and closing of three ancient oceans, namely Palaeo-Tethys, Meso-Tethys, and Ceno-Tethys [1]. Plutonisms in Southeast Asia are associated with the collision between continental plates and the subduction of oceanic plates below the continental ones. Intrusions in Southeast Asia are classified into several provinces. The Eastern Province was initiated by the Palaeo-Tethys subduction under Cathaysialand as a composite continent of the South China, North China, Indochina, West Sumatra, and West Burma plates. Granitoids in the Main Range Province are influenced by the collision of Sibumasu with East Malaya-Indochina, while the Western Province is related to Ceno-Tethys subduction [1].

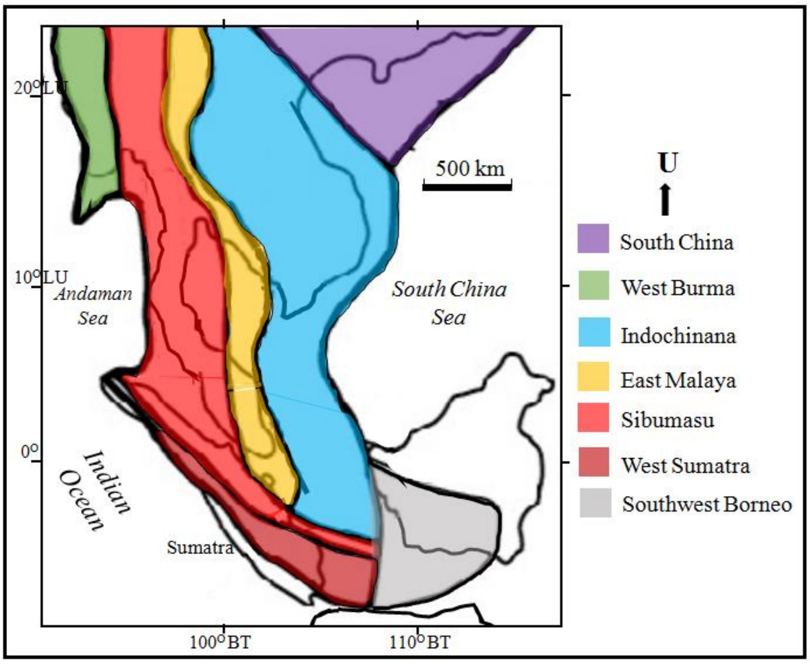

Figure 1. Continental plates in Southeast Asia (modified from [1])

Granitoid is one of the most common types of igneous rock used for research. The wide range of silica content, the variety of grain sizes, the various types of minerals that may be contained in it, as well as the variety of benefits are thought to be the driving interest for many types of research on this intrusive igneous rock. Moreover, the rock is useful in various economic aspects. The petrophysical, mechanical, electrical, and aesthetic properties make granitic rocks are often adapted to construct various cultural heritage buildings and art objects [2]-[6]. Several economic minerals, such as copper (Cu), silver (Ag), gold (Au), tin (Sn), and tungsten (W) are often present within granitic intrusions [7]-[10]. In comparison to other types of igneous rock, granite (especially the A-type) contains higher rare earth elements (REE) [11],[12]. Areas with granitic rock outcrops are attractive to mining activities due to the bauxitization and/or REE enrichment possibilities in the weathered horizons [13]-[18].

Granitoids are widespread in Sumatra. As described above, previous studies concluded that granitic rocks in Southeast Asia could be grouped into Eastern, Main Range, and Western Provinces [19],[20]. The intrusions located east of Bentong Raub Suture are considered the Eastern Province, such as on Bintan Island, Lingga Island, and some parts of the Bangka-Belitung region. On the other hand, granitoids found in the west of Bentong Raub Suture are classified in the Main Range Province, such as on Kundur Island, Singkep Island, and Bangka Island. The similarities of geochemical character and age of intrusion are the basis that Hatapang Granite is classified as a part of the Western Province [19]. Furthermore, there is a group of intrusive rocks located nearby Bukit Barisan Mountains which is called the Volcanic Arc Granites[10],[21]. This study aims to review the character of the granitoids in Sumatra and its surroundings as well as opportunities for their utilization. This study is useful for government and entrepreneurs in planning regional development.

THEORY

Plutonic Evolution in Sumatra

Cathaysialand consisted of several tectonic plates, namely Indochina, South China, North China, West Burma, East Malaya, and West Sumatra. The ancient Palaeo-Tethys ocean opened as a result of the separation of Cathaysialand from Gondwanaland in the Early Devonian [1]. I-type plutonism in the Eastern Province was triggered by Palaeo-Tethys subduction Cathaysialand during the Permian. While the convergence was taking place, some of the Cathaysialand composites separated and rotated. Palaeo-Tethys is thought to be close from the end of thePermian to Early Triassic [1],[22]. West Burma and West Sumatra plates then amalgamated with the western part of the Sibumasu plate during the Early Triassic [1]. The Medial Sumatra Tectonic Zone (MSTZ) was proposed as an imaginary boundary between the present-day Sumatra Island region originating from the West Sumatra and Sibumasu plates. West Burma and West Sumatra are now separated by the Andaman Sea.

Meso-Tethys opened due to the movement of the Cimmeria as a composite of the Sibumasu, South Qiantang, and Western Cimmerian, away from Gondwanaland towards Cathaysialand through Early Permian [1],[23]. Therefore, the closing of the Palaeo-Tethys was caused by two main factors, namely the subduction of this ancient sea under Cathaysialand and the opening of the Meso-Tethys. S-type plutonism in the Main Range Province is caused by the collision of Cimmeria and Cathaysialand, especially Sibumasu with East Malaya-Indochina since the Late Triassic[1],[24]. The Bentong Raub Suture was proposed as a representation of the extinct Paleo-Tethys and the separation between Eastern Province and Main Range Province in the Malaysian region through east Sumatra[1],[24],[25]. Meso-Tethys slowly narrowed due to Australian divergence, and was considered extinct in the Late Cretaceous [1].

Ceno-Tethys which opened during the Late Triassic and closed in the Late Cretaceous is another ancient sea that also subducted under Sibumasu and caused plutonism. This convergence is considered to be the trigger for plutonism in the Western Province [1],[22]. The granitic rocks of the Western Province are mainly located in the Burma area, so they are not discussed here. Subsequent magmatism occurring in the Volcanic Arc Granites was initiated by the subduction of the Indian-Australian Ocean below West Sumatra, which had amalgamated with Sibumasu. This magmatism led to the formation of volcanic and plutonic rocks, especially in the area now known as Bukit Barisan. The distribution of granite provinces in Sumatra can be seen in Figure 2.

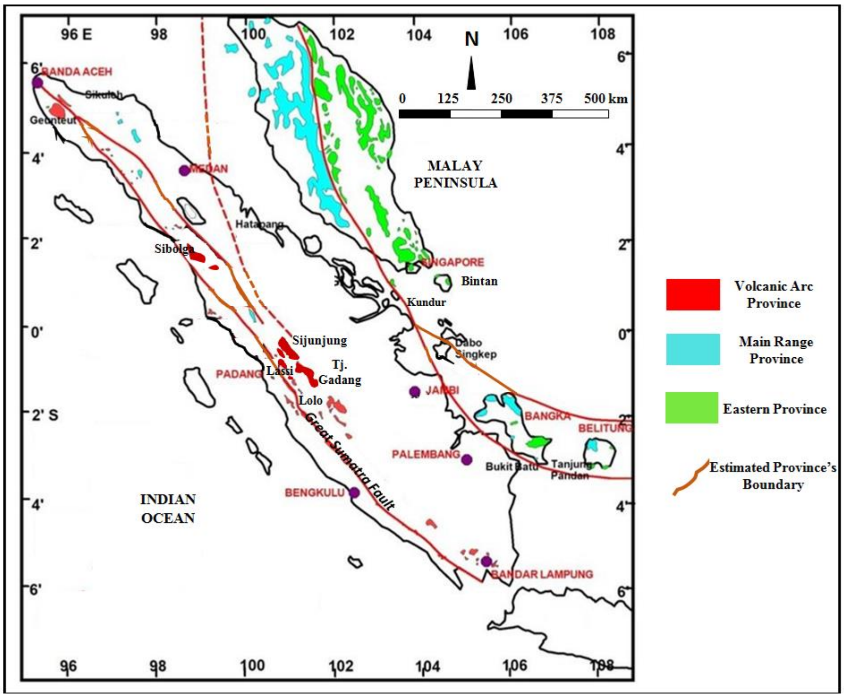

Figure 2. Southeast Asian granite provinces in Sumatra and its surrounding (modification from [1],[10],[20])

Granitoid Characteristics

Granitoid can be characterized based on the mineral contents, geophysical properties, and geochemical compositions. The condition of the granitic rock outcrops and the minerals contained within can be broadly identified through field observations. Microscopic studies are needed to determine the structure, texture, and mineral composition of rocks. Granitoids are generally holocrystalline. These rocks are mainly composed of quartz and feldspar along with some other accessory minerals, such as biotite, muscovite, hornblende, and pyroxene. Physically, granitic rocks have a hardness of 7 on the Mohs scale, compressive strength of 1180 – 2650 kg/cm^2, average density of 2.75 gr/cm^3, impermeable to water, and low coefficient of thermal expansion.

The major oxides composition of granitoids is generally examined using X-Ray Fluorescence (XRF) device, while the abundances of trace elements and REE are analyzed using Inductively Couple Plasma – Mass Spectrometry (ICP-MS). Although it requires a lower cost of analysis, the level of accuracy of Inductively Couple Plasma – Optical Emission Spectroscopy (ICP-OES) is lower than ICP-MS. The Atomic Absorption Spectroscopy (AAS) test method is more specifically used for the analysis of industrial metals and precious metals, such as Ag, As, Au, Cu, Fe, Pb, and Zn. In general, granitic rocks are igneous rocks formed in the subsurface with SiO_2 levels 50%.

METHODOLOGY

A research can use qualitative, quantitative, or Research and Development (R&D) approaches. Qualitative research examines an event, fact, or particular problem without proving a causal relationship or correlation of a problem or event. On the other hand, quantitative research method tends to be based on numerical measurements. R&D research departs from existing problems and then evaluates and develops a system to overcome these

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problems. This paper adapts a descriptive qualitative method on disclosure of granite rock intrusions around the Sumatra region and the opportunities that can be exploited from a scientific and economic perspective based on the results of previous research on Sumatran tectonics, granite evolution in Southeast Asia, geochemistry and the use of granite.

DISCUSSION

Building Materials and Artwork

Granitoids have been used by humans for shelter materials, cooking utensils, and weapons since the Stone Age. The Pokekea site in Central Sulawesi is one of the cultural heritages from the Megalithic period with objects made of granite-biotite [2]. The remains of the granitic rocks at the site have not changed much because the granite is resistant to temperature change and the salt water influences [3]. Granites are used in cultural heritages such as in the foundations and walls of Lawang Sewu (Figure 3a) in Semarang [6].

In general, cutting and polishing process is required to create a work of art from granitic rock. However, not all granitic rocks are suitable for making large buildings or monuments. Artists prefer without cracks or unaltered rocks that can interfere with the perfection of a work of art and can make it damaged more quickly due to weathering [4]. Therefore, granite for this purpose rarely comes from active tectonic areas which are very likely affected by weathering processes.

As described above, Sumatra is built two plates, namely West Sumatra and Sibumasu which are separated by MSTZ. In addition, there is also the Sumatran Great Fault with a direction almost similar to MSTZ [1],[20],[24]. Then, there is also the Bentong-Raub Sutur in the east of Sumatra. This condition makes it difficult to find large outcrops without fractures in Sumatra, especially near the three tectonic boundaries. This consideration may be the reason that the granites used for Lawang Sewu construction were imported from Europe [6], not from Sumatra, which is relatively close to Java. However, it does not mean that intrusive rocks in Sumatra are unuseful for the inhabitants. The rocks should be more valuable by adapting polishing technique to overcome the cracks for creating some smaller ornaments such as chairs, pavement tiles, inscriptions, and showers [4],[26] as shown in Figure 3b. Because of the durability, many shelters and worship buildings in Pulau Bangka are built of granite.

Figure 3. a) The granites used in building the Lawang Sewu actually originated from Europe.[6]; b) Cracks in granite can be overcome by polishing techniques so that they can be used as small expensive ornaments [26]

Mineralizations in Granitoid Intrusions

Minerals in granitoid are helpful to describe the rock type. Indonesia is one of the largest tin producers in the world due to the large amount of mineralization in correlation to S-type granite intrusions. The Bangka, Belitung, Singkep, and Kundur islands have a long history of tin mining since the colonial period to the present. The three Dutch-owned mining companies on the three islands were merged into a State-Owned Enterprise which is now known as PT. Timah Tbk [27]. Apart from these islands, tin is also found in the Isahan and Kampar regions [10],[28]. All of these areas are associated with granite in the Main Range Province region.

Copper, sometimes with gold, is a character of I-type granite. The high concentration of copper around Bukit Barisan region is due to the presence of ophiolite or calc-alkaline intrusive rocks [29]. The Au-Cu deposit which is in the endoskarn phase in the hematite-calcite-chlorite-albit-sericite-pyrite-chalcopyrite assemblage and sulfide veins in Pinang-Pinang, southern Aceh Province, is associated with granite intrusion [30]. Malachite as one of the copper-rich minerals can still be observed megascopically in the ex-mining area in X Koto Diatas District in the Sulit Air Granite domain [31]. Chalcopyrite mineralization occurs starting from a depth of 1.25 m above the surface in Nagari Aie Dingin, Solok Regency[9]. In Malaysia, Cu-Au-bearing intrusions are reported in Penjom, Bukit Tujuh, Bukit Damar, and Kemahang [32],[33].

Mineralization is affected by many factors, i.e. oxidation state and degree of fractionation. In granitic rocks, Cu-Au, Mo, and Sn minerals are associated with mafic, intermediate, and felsic spectra respectively [7]. Although both tend to be in oxidized magma, Cu-Au mineralization is more likely to be found in rocks with low fractionation levels while Mo at high ones. On the other hand, Sn is correlated with reduced magma with a high oxidation state. S-type granite crystallizes in reduced magma while I-type granite is in oxidized magma. Therefore, Cu-Au tends to be found in low fractionated I-type granite while the possibility of Sn mineralization (sometimes with W) in S-type granite increases with increasing degree of fractionation [7]. These factors can explain the presence of Cu-Au mineralization in the intrusions within East and Volcanic Arc Granites which are generally I-type, while Sn is more dominantly found in S-type of Main Range Province.

Rare Earth Elements in Granitoid

REEs are present in various types of igneous, sedimentary, and metamorphic rocks [10],[34],[35]. REEs are typically compatible elements which continue to be concentrated until the final phase of fractional crystallization. Quartz formed in the final stages of fractional crystallization as described in the Bowen Series. Therefore, REE tends to be higher in granitic rocks compared to other types of igneous rocks because these intrusive rocks contain minerals that solidify at the late stage of fractional crystallization. REE in igneous rocks is also more concentrated in alkaline-alkaline and carbonatite [10],[11],[15],[17]. Granitoids can be chategorized as alkaline rocks if the potassium and sodium oxides compositions are high enough to form alkaline minerals [36]. Carbonatite have never been found in Indonesia [28]. This explanation explains the number of REE studies on igneous rocks focused on granitic rocks in Indonesia, including Sumatra region.

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A-type granite, especially the alkaline one, was concluded to have the highest REE content compared to other alphabetical types [11],[12],[37],[38]. This is caused by the high temperature during the A-type formation process so that apatite and zircon are more easily dissolved to increase the levels of High Field Strength Elements including REE [12]. Increasing the degree of alkalinity further increases the abundance of REE in A-type granite. Comparing REE contents in S-type to I-type is quite complicated because of the unequal tendency between the two types of granite regarding their metaluminous/ peraluminous affinity to the degree of fractionation.

S-type granite is generally strong peraluminous whist I-type one is a metalluminous to weak peraluminous with A/CNK <1.1 [7],[12],[14],[21],[35]. However, there are several I-type intrusions with peraluminous characteristics which are simply indicated by the SiO_2 [39] content. At this high level of fractionation, the aluminous saturation index of I-type granite shows a positive correlation with the degree of fractionation, while S-type does not show a clear pattern. The aluminous saturation index is very influential on the solubility of REE-bearing minerals. Apatite is more easily dissolved in peraluminous magma, while this condition makes it difficult for monazite and zircon to dissolve [11],[40]. Apatite and monazite are relatively richer in light-REEs, while zircon is one of the minerals with a higher concentration of heavy-REEs [17],[41]. The increase in the light/heavy REE ratio during I-type fractionation can be explained by the dissolution character of the REE-bearing minerals to the peraluminous condition.

Separating REE bearing minerals from the fresh granite is expensive due to its hardness. The outcrop needs to be heated by traditional miners so that the rock can be cracked as shown in Figure 4. Therefore, the REE exploitation is considered less prospective if it is done at the fresh outcrop directly except for the A-type. However, there is no specific association of A-type intrusion to any granite provinces in Southeast Asia. A-type granite was identified in Besar Island, Malaysia [37] and Karimun Island [20],[38], which are located in Eastern Province and Main Range one, respectively. This type of granite which tends to be ferroan is also found in several Sibolga Granite facies [10]. Thus, REE exploration of granitic rocks in Sumatra is not easy because the anarogenic nature of A-type granite is not directly related to general regional tectonics.

Figure 4. A traditional granite mining sites on Belitung Island. Miners need to heat the granite so it is easier to be cut

Metal Enrichment on the Weathering Horizon

Sumatra is vulnerable to weathering because it is located in a relatively active tectonic area and a tropical climate. The chemical composition of the weathering horizon depends on the type of parent rock. Laterites with increased levels of nickel, chromium, manganese, and cobalt are found in the weathering of ultramafic rocks such as in the North Konawe [42]. Bauxitization is caused by the transport of Si to the saprolite horizon and the transfer of Al and Fe to the laterite horizon. Previous research on bauxitization due to weathering of granite in Sumatra has been carried out on Bintan Island [13] and Selayar Island [18], both of which are located in Eastern Province as shown in Figure 5a. The lack of research on bauxite formation in Main Range Province is because the granite investigation there is focused on tin mineralization. On the other hand, a good granite weathering horizon is difficult to find in the Volcanic Arc Granites because the intrusion is generally formed in the Middle to Late Mesozoic. The granites are also located in mountainous areas so that the weathering horizon is easily disturbed by erosion.

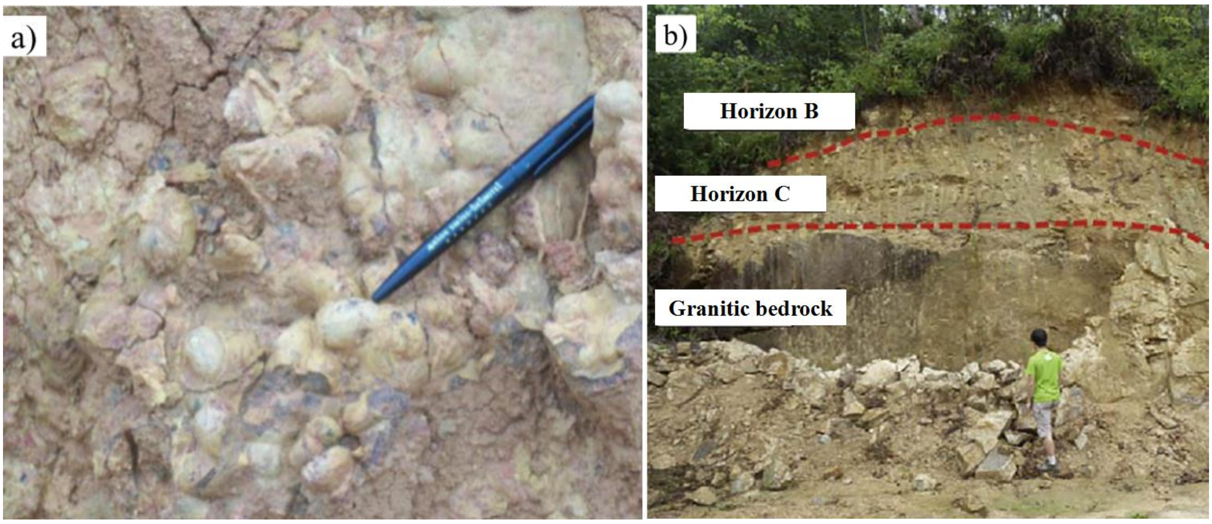

Figure 5. Economic aspects occur in the granite weathering horizons; a)Bauxite [18]; b)REE enrichment [15]

The REE enrichment in the laterite horizon is caused by the mobilization of rock-forming ions and the deposit is known as an ion-absorption type deposit as can be seen in Figure 5b. This type of REE deposit is interesting because the material is softer and contains lower levels of U-Th in comparison to the parent rock [15]. This type of deposit is initiated by the REE release from the granitic parent rock, resulting in the formation of ionic complexes which are then absorbed in the weathered layer, especially in the horizon below the soil [14],[15],[17]. China is rich in ion absorption type deposits due to the presence of several large-scale tectonic structures and climatic conditions. Although similar tectonic and climatic conditions can be found in Southeast Asia, weathering processes can continue well in China due to minimum erosion factors [15]. This process resulted in significant heavy-REE enrichment in China, as in Jiangxi, Hunan, Fujian, Guangdong, and Guangxi [15],[43]. On the other hand, the medium-REE is actually more enriched in deposits of a similar type in Southeast Asia, such as in Kuantan [44] and Phuket [14]. The difference is influenced by the REE bearing minerals in the host rock in each weathering profile. The REE enrichment scheme for the granitic weathering horizon is shown in Figure 6.

There has been no clear conclusion regarding the tendency of bauxite or REE enrichment on weathered granite. Bauxitization and REE enrichment might occur simultaneously as detected in Greece

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[16] and India [34]. Mining company can choose which commodities to mine based on consideration of grade, reserves, and cost. It should be noted that if bauxite is selected as a mining commodity, the waste is might economically valuable because of the high REE content [8].

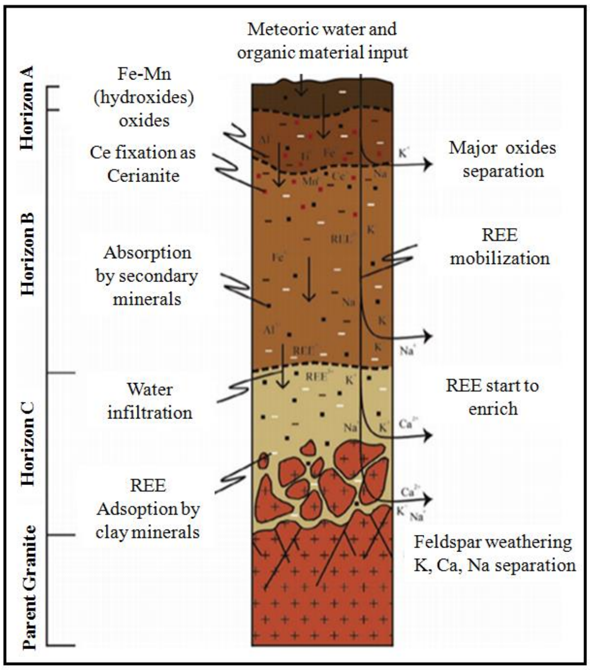

Figure 6. REE mobilization scheme which initiate enrichment in one of the weathering horizons.

Uranium and Thorium in Granite

Uranium is found in a wide variety of rock types and environmental conditions with the abundance hundreds times higher than gold in the earth's crust. Uranium (U) and Thorium (Th) in granite, especially pegmatite granite, is greater than other igneous rock types. The enrichment is caused by the incompatible character of U and Th so that it is concentrated at the end of the magma crystallization process. S-type granite is suspected as a uranium carrier because it is formed through compression of sediments that can absorb these elements in the continental crust [45].

Hatapang granite and several S-type granite groups on Bangka Island indicate high U and Th concentrations up to >1,300 ppm and >13,000 ppm in heavy mineral concentrates, respectively [46],[47]. As already described, S-type granite is also highly correlated with tin mineralization. Tin processing tailings contain high U and Th compositions because of monazite mineral in these materials [48]. Trioctylamine is applied on extracting 67% U and 0.84% thorium from tin tailings in Bangka [49]. U migration might occur in the weathering process of S-type granite to form a new Uranium phase [50]. However, a research on U mobilization of S-type granite weathering is not available yet.

CONCLUSION

The granitoids in Sumatra and surrounding areas are grouped into Eastern, Main Range, and Volcanic Arc Provinces, which are dominated by I-type, S-type, and I-type rocks, respectively. The formation of the granite provinces is related to the evolution of three ancient oceans, namely: Palaeo-Tethys, Meso-Tethys, Ceno-Tethys. Unaltered, uncracked, fresh, and large granite outcrops on Sumatra are difficult to find due to the presence of several fault zones. Tin mineralization is potentially found in S-type granite of the Main Range Province region, while copper-silver-gold tends to be associated with I-type granite in the other two provinces. Completely weathered granite profile is more likely happens in the islands at the east of Sumatra than on mainland due to the age of the intrusion with less erosional effects. Granitoids from Sumatra can be adapted as small ornaments with polishing techniques. REE exploration of fresh granite host rock is considered less prospective due to its physical properties, except for A-type granite. Granite weathering horizons needs further attention because it can lead to enrichment of both bauxite and REE. Exploration of radioactive elements can be directed at S-type intrusions due to the high U and Th composition in the source rock and in the associated tin tailings. This work can be a consideration for the national and regional governments with granite intrusion in making strategic steps for the region and the nation.

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