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Petrogenesis of Pre-Tertiary A-Type Granitoid in Jambi Area and its Implications of Rare Earth Element Potential on Main Range Sumatra Belt

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Abstract

Granitoid rocks are one of the main sources of rare earth elements (REE). This makes granitoid characterization become important in the early stages of REE exploration. Almost all granitoids in Indonesia have been mapped. However, more detailed granitoid studies in Indonesia are still focused on Bangka and Belitung granites (tin belt granite). In contrast to Bangka and Belitung granites, studies related to petrogenesis and granite characteristics on the mainland of Sumatra Island (Sumatra Main Range) are rarely done, such as granitoid in Jambi area. The aim of this study is to determine the characteristics of the Pre-Tertiary granitoids located in the Tigapuluh and Duabelas Mountains, Jambi. The Tanjungjabung Barat granitoid represent the Tigapuluh Mountains area while the Sarolangun granitoid represent the Duabelas Mountains area. These two granitoids interpreted to be Triassic to Jurassic in age. Granitoid characteristics include petrological and geochemical characters. This study also focuses on the petrogenesis of Pre-Tertiary granitoid and its implications for the abundance of REEs. Megascopic observation, petrographic, and geochemical analysis are done in this study. Geochemical analysis was done at the Center of Geological Survey Laboratory, Bandung using the ICP-MS Thermo Icap-Q and XRF ADVANT XP Thermo ARL9900 instruments. Based on megascopic and petrographic observations, both of the granitoids are classified as granite. Geochemically, these two granitoids show the character of A-type granite which is formed in the post-collision environment, and derived from the crustal melting with ferrous alkalic to alkali-calcic peraluminous affinities. This crustal melting happened due to the collision of the Sibumasu Block with Indochina resulting in crustal thickening and crustal melting. The magma then contaminated effectively in the rift environment due to the subduction roll-back of Meso-Tethys in the Late Triassic. Subduction in the West Sumatra also play roles in the genesis and it is shown by the geochemical character of the Sarolangun granitoid. Effective contamination derives the characteristics of A-type granite so that the REE content in both granites are abundant. The abundance of REE is indicated by the presence of the allanite, monazite, apatite, zircon, and titanite. The REE concentration of the Sarolangun granitoid reaches 330 ppm, while the Tanjungjabung Barat granitoid reaches 261 ppm. The REE concentrations of A-type granitoid in Jambi then compared with A-type granitoids from the world and showed relatively the same REE concentrations. The REE concentrations of these granitoids are also higher than the other type granitoids in Indonesia. However, the REE concentrations of Jambi granitoids are similar to the fractionated S-type granite in Bangka. With a recent study showing the presence of A-type granitoid in Sarudik (North Sumatra) and Bukit Batu (South Sumatra), the A-type granitoid in this study indicates the existence of A-type granitoid belt in the Sumatra Main Range. This belt will have a high abundance of REE concentrations and potentially become the source for REE deposits. The author hopes that this study could improve the understanding of tectonic in Sumatra and suggestion for REE exploration in the area.

Keywords: Petrogenesis, A-Type Granitoid, REE, Jambi

INTRODUCTION

Currently, rare earth elements (REE) are an important commodities for the high-technology industry, metal alloys, chemical catalyst, and etc. (van Gosen, 2017). Granitoid rocks are one of the main sources of REE, especially the A-type granitoids (Eby, 1992; Cuney, 2014; van Gosen, 2017) and fractionated S-type and I-type granitoids (Whalen et al., 1987; Cuney, 2014). This makes granitoid characterization become important in the early stages of REE exploration. In Indonesia, almost all of the granitoid rocks have been mapped (Wikarno et al., 1984). Cobbing (2005) have already divided the granite province in Sumatra into main range, volcanic arc, and eastern province. In this paper, the main range and volcanic arc province are considered as Sumatra main range granite and eastern province are considered as tin island granite. The tin belt granite have been studied in more detail especially in Bangka and Belitung (Cobbing et al., 1992; Schwartz et al., 1995; Cobbing, 2005). However, the studies related to petrogenesis and granite characteristics on the mainland of Sumatra Island (Sumatra Main Range) are rarely done, such as granitoid in Jambi area.

Some previous detailed studies that are conducted in the Sumatra main range are research from Setiawan et al. (2017) and Zhang et al. (2020) in Sibolga Complex, North Sumatra and Destrayuda (2015) in Bukit Batu, South Sumatra. All of the previous research show indication of the occurrence of A-type granite belt which is marked by the presence of A-type granite characteristic (geochemistry and mineralogy) in both areas. To confirm the occurrence of A-type granitoid belt in Sumatra main range, the study on the batholit between both area must be conducted.

This study aim to determine the characteristics of granitoids located in the Tigapuluh and Duabelas Mountains, Jambi that are situated between both area. Both granitoids are expected to be Jurassic age (Wong, 1979 in Simandjuntak et al., 1991). The study include the petrological and geochemical characters, and also the petrogenesis of the granitoids and its implications of REE potential. This study also seek the mineral that gives major contribution for the abundance of REE on both granitoids. The granitoid then compared to another granitoids in Indonesia (Ng et al., 2017; Irzon, 2017; Setiawan et al., 2017; Ansori et al., 2019; Zhang et al., 2020) and the world (Vilalva and Vlach, 2014; Moreno et al., 2014; Ghani et al., 2014; Cámera et al., 2018; Jia et al., 2019) to see the commerciality of the granite.

Geological Background

As the introduction have already mentioned earlier, our research is located in Tigapuluh and Duabelas Mountains. Both of the locations are located in different tectonic block. Based on the tectonic blocks distribution in Southeast Asia, Tigapuluh Mountain is situated in the Sibumasu Block (East Sumatra Block), while Duabelas Mountain is situated in the West Sumatra Block. These block is bounded by the Medial Sumatra Tectonic Zone (MSTZ; Barber et al., 2005; Barber and Crow, 2005; Barber and Crow, 2009). These continental blocks consist different lithologies that are possible to affects the intruding granite composition.

The Sibumasu Block is characterized by Viséan temperate faunas and the occurrence of pebbly mudstones (Barber et al., 2005;

Barber and Crow; 2009). This pebbly mudstones is represented by Mentulu formation in Tigapuluh Mountains that interpreted as tillite deposits (Figure 1; Suwarna et al. 1994; Simandjuntak et al. 1991; Barber et al., 2005; Barber and Crow, 2005; Barber and Crow, 2009). These characteristics indicates that the Sibumasu Block derived from the separated Gondwana Block in the glacial environment, at the same time with the opening of Meso-Tethys in the Early Permian by extension, rifting, and formation of new oceanic crust (Barber et al., 2005; Barber and Crow, 2009).

In contrast to Sibumasu Block, the West Sumatra Block has similarities to the Cathaysia Block, that are characterized by tropical Viséan coral-algal fauna and flora found on the limestones in the Kuantan Formation (Barber et al., 2005). In Duabelas Mountains, the Terantam Formation, that consist of low degree metamorphic rock, are correlated with the Kuantan Formation (Figure 1; Simandjuntak et al. 1991; Barber et al., 2005).

The boundary between Sibumasu block and the West Sumatra block, MSTZ, consist of intensively deformed rocks that is represented by the Gangsal Formation of the Tigapuluh Group at the southwestern of Tigapuluh Mountains in the research area (Figure 1; Simandjuntak et al. 1991; Barber and Crow, 2005; Barber and Crow, 2009). This zone is interpreted as a major transcurrent shear zone between the Sibumasu and West Sumatra blocks that was caused by westwards movement of West Sumatra Block from the Cathaysia to the present position. The seafloor spreading of Meso-Tethys in the Late Permian-Early Triassic perhaps is the driving force for the movement (Barber et al., 2005; Barber and Crow, 2009).

Besides the complex continental block that compose the Sumatra Island, the amalgamated block then cutted and intruded by multiple volcanism and plutonism episodes (Wikarno et al., 1984; Barber and Crow, 2009; Zhang et al., 2020). The Mesozoic-Tertiary episodes have been comprehensively explained by McCourt et al. (1996). Granitoids in Tigapuluh and Duabelas Mountain are two of the products of Triassic-Jurassic plutonism (Figure 1; Wong, 1979 in Simandjuntak et al., 1991) or Episode B-B1 (McCourt et al., 1996). The episode B1 was marked by the collision of Sibumasu Block with East Malaya (Indochina) that recorded along Bentong-Raub Suture. Crustal thickening, as the result of the collision, produce magmatism that are distributed on the eastern Sumatra (McCourt et al., 1996). The magmatism of episode B1 derives S-type and I-type granite that are known as Eastern Province and Main Range Province (Figure 2; Cobbing, 2005; Zhang et al., 2020). Recently, this granite are extracted and commonly referred as “tin granite belt” (Ng et al., 2017). The episode B (McCourt et al., 1996) is represented by volcanic arc magmatism, which relate to the subduction of Meso-Tethys beneath the western margin of Sumatra (Katili, 1989; McCourt et al., 1996; Barber et al., 2005; Cobbing, 2005; Hutchison, 2014). The magmatism produce the I-type granite on the western Sumatra that are commonly referred as volcanic arc provinces (Cobbing, 2005; Zhang et al., 2020).

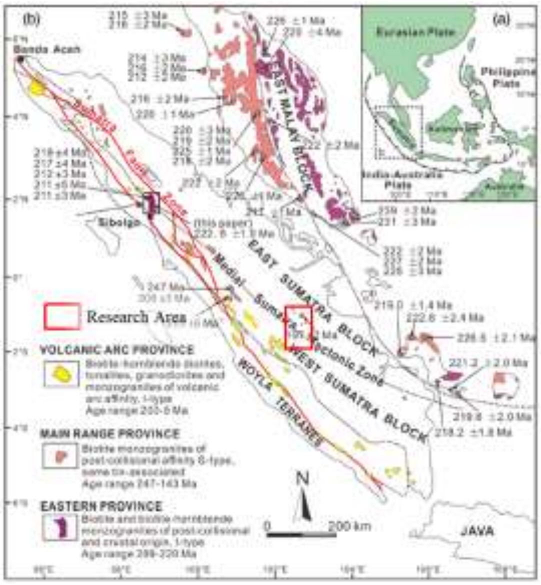

Figure 2. The granitoids distribution in Sumatra that could be divided into three different provinces such as Volcanic Arc Province, Main Range Province, and Eastern Province (Cobbing, 2005 in Zhang et al., 2020)

All the granites from the episodes have been mapped (Cobbing, 2005) and the detailed studies are mostly carried out on the tin island granite. The previous studies that were carried out on the research area were conducted by Schwartz and Surjono (1990) in Sungei Isahan, Tigapuluh Mountains. The study suggest that the granitoid in Tigapuluh Mountains have the similar geochemical characteristics of the granitoid Main Range Province from Peninsular Malaysia and Thailand (Figure 2; Cobbing, 2005 in Zhang et al., 2020).

Moreover, recent studies also suggest the occurrence of A-type granitoids. These granitoids occurred on the Karimun Island, Riau (Irzon, 2017) and on the Sumatra main range. Detailed studies in the Sumatra main range, precisely in Sibolga Complex, North Sumatra which have been conducted by Setiawan et al. (2017) and Zhang et al. (2020). The occurrence of A-type granite in South Sumatra, specifically Bukit Batu, have been reported by Destrayuda (2015). These studies are important for the tectonic reconstruction of Sumatra due to the A-type granite could be an indicator of rifting environment on the Late Triassic to Early Jurassic (Eby, 1992; Frost and Frost, 2011).

METHODOLOGY

Granitoid samples have already taken from Tigapuluh mountains which are represented by Tanjungjabung Barat granitoid and from Duabelas mountains that represented by Sarolangun granitoid (Figure 1). A total of 13 fresh granitoid samples were collected from both granitoid, with specification of five samples from Tanjungjabung Barat granitoid, and eight samples from Sarolangun granitoid.

Geochemical analyses were performed in the Center of Geological Survey laboratory, Bandung. All of the 13 granitoid samples were selected for X-Ray fluorescence analyses (XRF) using ADVANT XP Thermo ARL9900 instruments. Before the samples are being analyzed by the instrument the samples must be prepared as follows. The samples are weighed as much as 5 gram. Then, 1 gram of binder is added and crushed until the samples and binder are mixed. The samples then pressed with boric acid as the mixture until the pressed samples are ready to be analyzed with the instrument.

In addition, induced coupled plasma-mass spectrometry (ICP-MS) are also done using Thermo Icap-Q instrument. The analysis was carried out on six granitoid sample, specifically four Tanjungjabung Barat granitoid samples and two Sarolangun granitoid samples. Before ICP-MS analysis was carried out, the samples were being prepared with Center of Geological Survey laboratory procedures. First, the samples are crushed into 200 mesh in size. Then, the samples are being leach with mixture of formic acid (HF), nitric acid (HNO_3), and perchloric acid ($HClO_4$) at 120°C to evaporate the acid. Finally, nitric acid was added to digested samples. The samples are ready for ICP-MS analysis.

RESULTS AND DISCUSSION

Petrography

Based on field observation, the Tanjungjabung Barat granitoids are gray with medium-grained crystals (Figure 3). Petrographically, these granitoids are classified as granite *sensu stricto* (Figure 4; Streckeisen, 1976 in Gill, 2010). It consist of K-feldspar, quartz, plagioclase, biotite, and minor hornblende and titanite (sphene; Figure 5a). Allanite, monazite, zircon, apatite, and opaque minerals are found as accessory minerals (Figure 5b, 5d, and 5e). In addition, sericite and chlorite also found in the partly altered of feldspar and biotite minerals (Figure 5c and 5d). Some of the K-felspar minerals in this granite occurred as microcline and show exsolution texture as perthite. The granite also show granophyric texture (Figure 5c) and zoning in plagioclase (Figure 5f).

Figure 3. a) Outcrop of Tanjungjabung Barat granitoid situated in waterfall; b) The granitoid from the outcrop have a medium-grained crystals and reddish gray in color; c) The granitoid have a medium-grained crystals and gray in color.

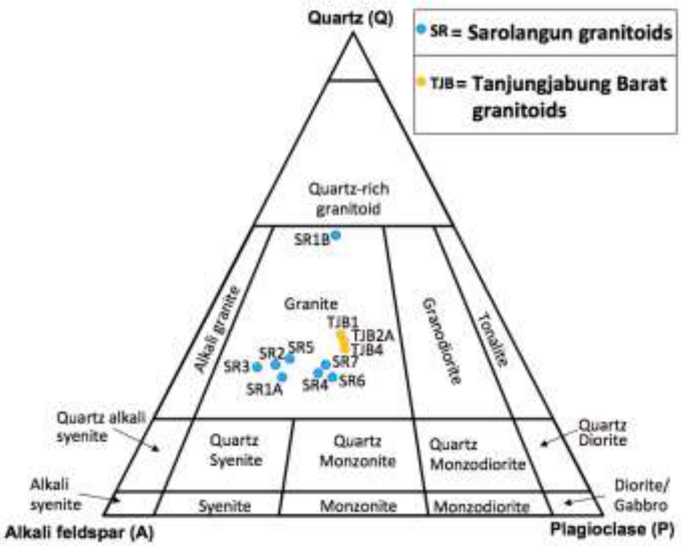

Figure 4: Plutonic rock classification based on relative proportions of alkali feldspar, plagioclase, and quartz (Streckeisen, 1976 in Gill, 2010). All of the granitoids on this study are classified as granite *sensu stricto*.

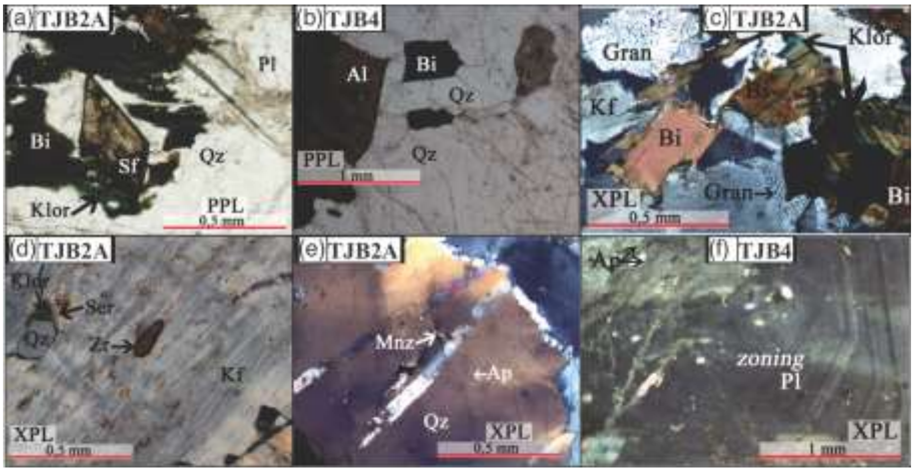

Figure 5. The photomicrographs of Tanjungjabung Barat granitoid; a) the presence of sphene mineral; b) allanite; c) granophyric texture and chlorite minerals, chlorite partly altered of biotite minerals; d) the inclusion of zircon in K-feldspar minerals were partly altered by sericite; e) inclusion of monazite in quartz; f) zoning plagioclase slightly found in this granite.

On the other hand, hand-specimen of Sarolangun granitoids have a darker grey in color with medium-grained crystals (Figure 6). Based on petrography analysis, they also classified as granite *sensu stricto* (Figure 4; Streckeisen, 1976 in Gill, 2010) that are composed by K-feldspar, quartz, plagioclase, biotite, muscovite, pyroxene, and have more hornblende and titanite (Figure 7). Accessory minerals such as allanite, monazite, zircon, apatite, and opaque minerals have relatively more abundant compared to the Tanjungjabung Barat granite (Figure 8 and 9b). Pyroxene occurred as clinopyroxene, and aegirine and aegirine-augite also found on the thin section. Some feldspar and biotite were partly altered by sericite and chlorite (Figure 9a). Most K-felspar minerals in this granite were present as microcline and they have more perthite and granophyric texture than Tanjungjabung Barat granites (Figure 10a). In addition, one of these granite samples shows the hornblende mineral that riming clinopyroxene (Figure 10b). This rim texture also observed in the opaque mineral that rimmed by titanite (Figure 10c).

Figure 6. a) The outcrop of Sarolangun granitoid situated in waterfall; b) The granitoid show relatively reddish gray in color; c) The granitoid have a darker grey in color with medium-grained crystals.

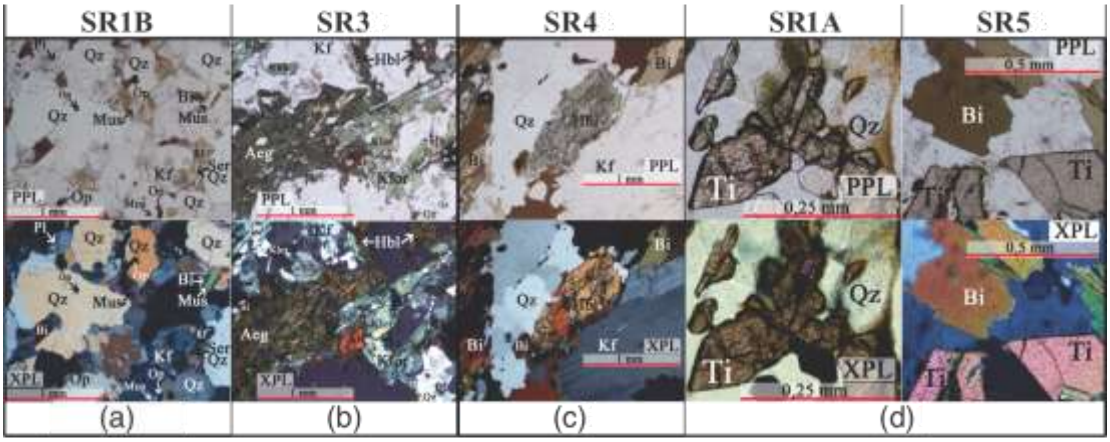

Figure 7. The photomicrographs of Sarolangun granitoid; a) the presence of muscovite; b) aegirine; c) polysynthetic twinning in hornblende; d) titanite.

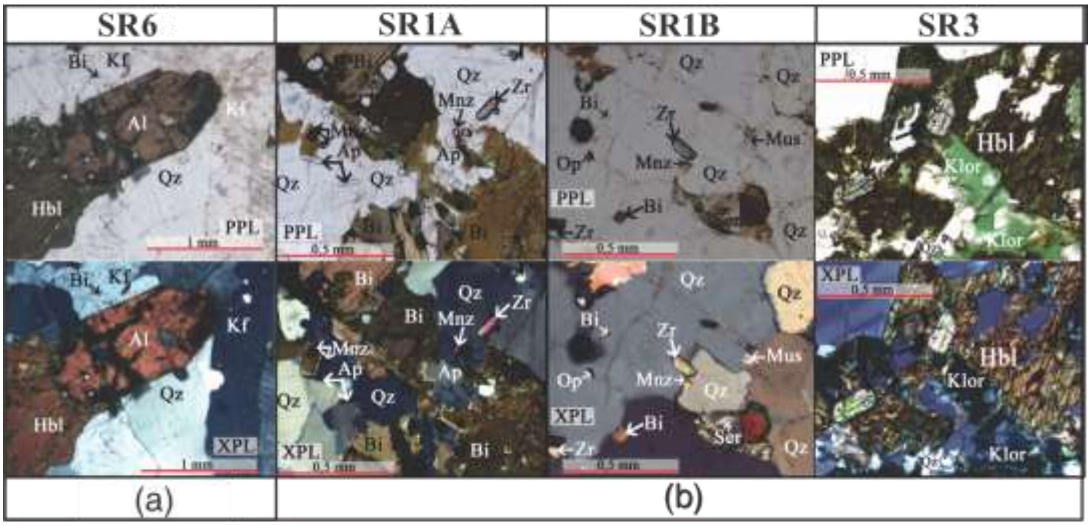

Figure 8. The photomicrographs of Sarolangun granitoid; a) The presence of allanite; b) In this granite, the inclusion of zircon relatively more abundant than in the Tanjungjabung Barat granite.

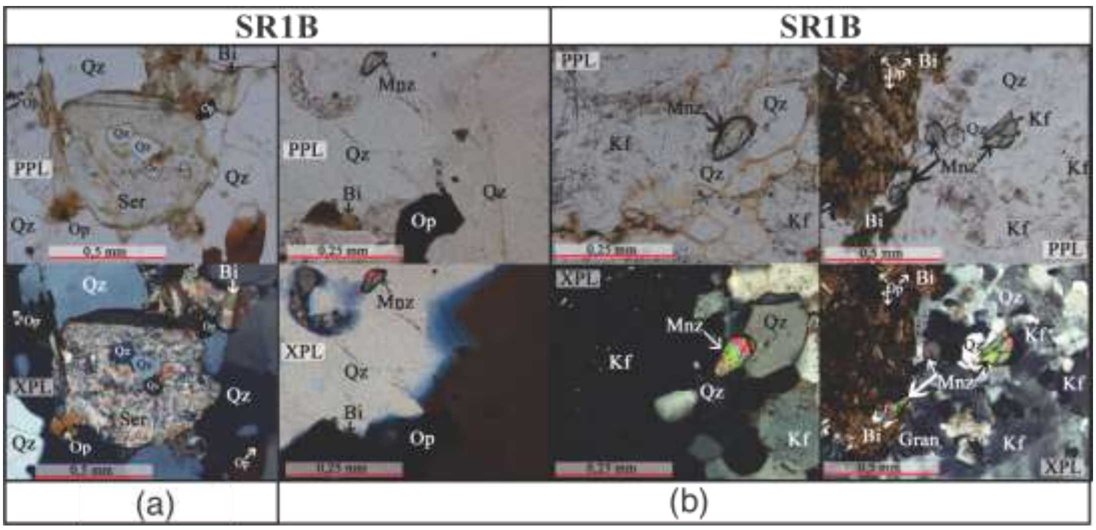

Figure 9. The photomicrographs of Sarolangun granitoid; a) One of the samples in Sarolangun granitoid shows the high amount of sericite mineral, in this sample feldspar mineral mostly altered by sericite; b) Sarolangun granitoid also have more inclusion of monazite than the Tanjungjabung Barat granitoid.

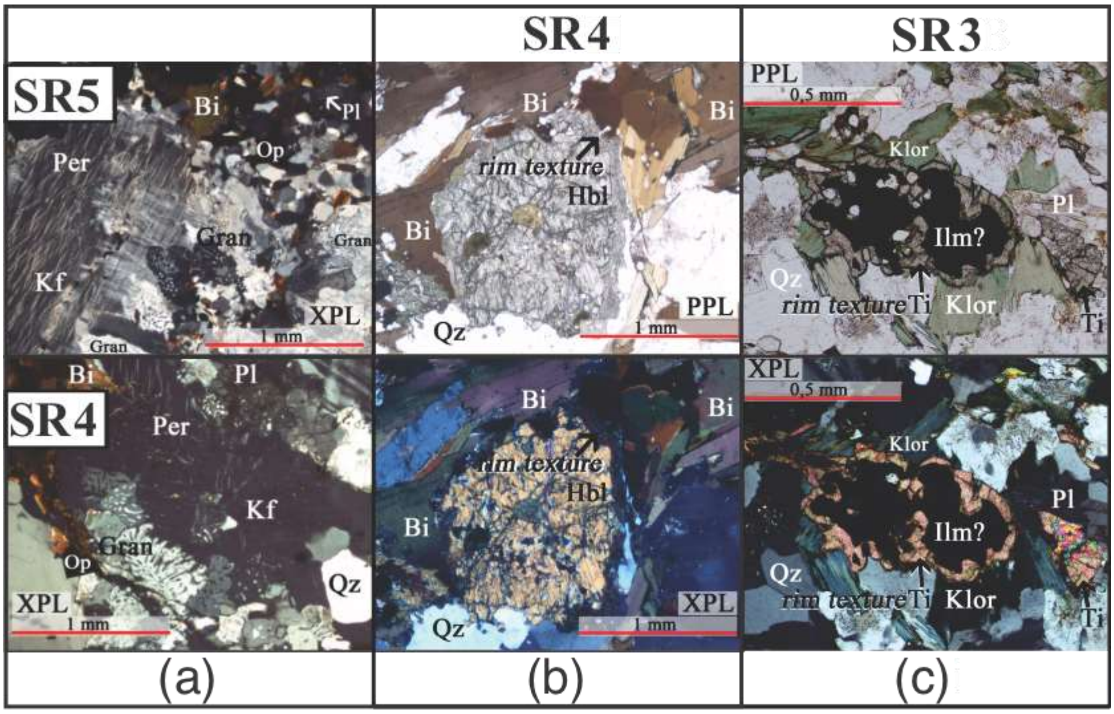

Figure 10. The photomicrographs of Sarolangun granitoid; a) The presence of perthite and granophyric texture; b) One of the Sarolangun granitoid samples shows the hornblende mineral that riming clinopyroxene; c) Rimmed texture also observed in the opaque mineral that rimmed by titanite.

Major Element Geochemistry

Geochemical data includes the major and trace element data that were obtained from XRF analysis. The data are provided in Table 1 and 2. The XRF analysis shows that the loss on ignition (LOI) values from all rock samples (except SR6) ranges from 0.33 to 1.67%, indicating that the samples are fresh (LOI <2%). There is one sample that shows LOI values of 20.52% (SR6; Table 2). However, direct observation (visual) from the SR6 sample suggest if the sample still in fresh condition so that it can still be entered for next data processing. Moreover, the total amount of the major element content (include LOI data) from XRF analysis are around 99.8%, within tolerance limits (100 ± 2%). It suggest that the XRF analysis results are good or precise so that the results of the geochemical analysis can be used for further analysis.

Table 1. The major element compositions data of the Tanjungjabung Barat granitoids.

Major element (weight %)	Tanjungjabung barat granitoid				
	TJB1	TJB2A	TJB2B	TJB3	TJB4
LOI	1.21	0.88	0.98	1.58	0.59
Correction factor	1.012	1.009	1.010	1.016	1.006
SiO_2	71.24	69.39	67.30	69.84	68.91
Al_2O_3	14.22	13.71	13.58	15.25	14.11
Fe_2O_3	3.84	4.37	7.38	3.43	4.25
K_2O	5.41	5.44	4.69	5.78	5.71
Na_2O	2.61	2.69	2.08	2.44	2.64
CaO	1.189	2.544	1.401	1.808	2.438
MgO	0.4171	0.7425	2.070	0.4542	0.8138
TiO_2	0.5192	0.5236	0.8285	0.4699	0.5412
P_2O_5	0.1378	0.1486	0.1539	0.1063	0.1571
BaO	0.0287	0.0401	0.0661	0.0504	0.0517
MnO	0.0834	0.0887	0.1139	0.0489	0.0896
Cl	-	-	-	-	0.007
ZrO_2	-	0.0085	0.0113	-	-
SrO	-	-	-	-	-
Rb_2O	0.04	0.04	0.03	0.04	0.04
CeO_2	-	-	-	0.02	-
La_2O_3	0.0083	0.0060	0.0064	0.0093	0.0070
V_2O_5	0.0054	-	0.0159	0.0058	-
ZnO	0.0102	0.0089	0.0092	0.0071	0.0073
Cr_2O_3	0.0113	0.0118	0.0172	0.0096	0.0102
Nb_2O_5	0.0033	0.0037	-	-	-
PbO	-	-	-	-	0.0049
Ga_2O_3	0.0028	0.0022	0.0026	0.0026	0.0030
Y_2O_3	-	0.0059	-	0.0057	0.0061
SO_3	0.0241	0.0260	0.0499	0.0258	0.0172
NiO	-	-	0.0050	-	-
Total	99.80	99.80	99.81	99.80	99.81

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Table 2. The major element compositions data of the Sarolangun granitoids.

Major element (weight %)	Sarolangun granitoid							
	SR1A	SR1B	SR2	SR3	SR6	SR7	SR4	SR5
LOI	0.55	0.94	1.40	1.67	20.52	1.60	0.33	0.73
Correction factor	1.006	1.010	1.014	1.017	1.259	1.016	1.003	1.007
SiO_2	60.71	86.51	64.57	60.67	60.69	61.36	59.82	59.21
Al_2O_3	17.02	7.02	19.68	17.06	14.88	15.44	15.37	16.95
Fe_2O_3	7.33	2.39	2.04	8.15	7.35	8.81	9.67	8.44
K_2O	5.41	2.15	6.22	5.30	5.60	4.00	4.23	5.39
Na_2O	3.46	0.58	4.10	4.09	3.29	2.90	3.20	3.29
CaO	2.909	0.1260	1.714	1.957	3.795	3.689	3.602	3.163
MgO	1.166	0.5451	0.2512	1.178	2.106	1.535	1.503	1.234
TiO_2	0.7987	0.3493	0.6004	0.6486	1.114	1.013	1.177	0.9413
P_2O_5	0.4018	0.0664	0.2726	0.3347	0.3866	0.5305	0.5934	0.4976
BaO	0.1629	-	0.1035	0.1013	0.1536	0.1433	0.1375	0.1904
MnO	0.0994	0.0154	0.0280	0.0880	0.1091	0.1118	0.1314	0.1276
Cl	0.0946	-	-	0.0054	0.0894	0.0250	0.1023	0.1179
ZrO_2	0.0534	-	0.0818	0.1068	0.0541	0.0664	0.0681	0.0613
SrO	0.0489	-	0.0417	0.0395	0.0443	0.0494	0.0403	0.0602
Rb_2O	0.0313	0.0081	0.0248	0.0281	0.0295	0.0211	0.0256	0.0299
CeO_2	0.0197	-	0.0209	-	0.0146	-	0.0159	-
S	0.0153	0.0073	0.0092	-	0.0281	-	-	-
La_2O_3	0.0122	-	0.0162	0.0100	0.0097	0.0100	0.0070	0.0097
V_2O_5	0.0118	0.0071	0.0104	-	0.0122	0.0147	0.0178	0.0107
ZnO	0.0109	0.0045	0.0037	0.0121	0.0102	0.0131	0.0150	0.0101
Cr_2O_3	0.0085	0.0218	0.0071	0.0038	0.0094	0.0092	0.0093	0.0066
Nb_2O_5	0.0068	-	0.0053	0.0085	0.0064	0.0062	0.0073	0.0074
PbO	0.0041	-	-	-	-	-	-	-
Co_3O_4	0.0039	-	-	-	-	0.0032	0.0037	-
Ga_2O_3	0.0037	-	0.0032	0.0031	0.0026	0.0028	0.0031	0.0043
Y_2O_3	-	-	0.0053	0.0042	-	-	0.0047	-
SO_3	-	-	-	0.0271	-	0.0458	0.0487	0.0378
I	-	-	-	-	-	0.0112	-	-
Nd_2O_3	-	-	0.0105	-	0.0084	-	-	-
Total	99.80	99.80	99.81	99.81	99.79	99.82	99.80	99.80

All samples of Tanjungjabung Barat granitoid have high SiO_2 content ranging from 67.30 to 71.24 wt.%, with an average of 69.34 wt.% (n=5). They also have high content in K_2O (4.69-5.78 wt.%), Na_2O (2.08-2.69 wt.%), and Al_2O_3 (13.58-15.25 wt.%). The content of $Fe_2O_3^{(total)}$ in this granitoid is also high ranging widely from 3.43 to 7.38 wt.%. Other major elements are also present, such as MnO (0.05-0.11 wt.%), MgO (0.42-2.07 wt.%), CaO (1.19-2.54 wt.%) , TiO_2 (0.47-0.83 wt.%), and P_2O_5 (0.11–0.16 wt.%).

Sarolangun granitoid, however, shows lower SiO_2 concentration than the Tanjungjabung Barat granitoids with range widely from 59.21 to 67.39 wt.%. One sample have a very high SiO_2 concentrations (86.51 wt.%) in SR1B sample. The high SiO_2 content are consistent with the high quartz content in petrographic analysis. All samples shows high K_2O (4-6.22 wt.%) and Na_2O (2.90-4.10 wt.%), with Al_2O_3 varying content from 14.88-19.68 wt.%. In contrast, the SR1B sample has lower concentration of K_2O (2.15 wt.%), Na_2O (0.58%), and Al_2O_3 (7.02 wt.%). This granitoid has a high content of $Fe_2O_3^{(total)}$ (2.04-9.67 wt.%). The other major elements data that obtained were MnO (0.02-0.13 wt.%), MgO (0.25-2.11 wt.%), CaO (0.13-3. , 80 wt.%), TiO_2 (0.35-1.17 wt.%), and P_2O_5 (0.06–0.59 wt.%).

From the major element geochemistry data, Sarolangun granitoid, which is younger than Tanjungjabung Barat granitoids, shows lower content of SiO_2, and have more higher content of Fe_2O_3, CaO, MgO, TiO_2, P_2O_5, and ZrO_2 compared to the Tanjungjabung Barat granitoids.

Trace Element Geochemistry

Beside major element, trace element also provided in Table 3. It could be seen that both granitoids are enriched in high field-strength elements (HFSE), large ion lithophile element (LILE), and rare earth element (REE). Commonly, REE could be divided into two groups which are light REE (LREE) and heavy REE (HREE). In this research, LREE consists of lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), and europium (Eu), while the HREE consists of gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu). The Tanjungjabung Barat granitoid has a high REE concentration in total, ranging from 207 to 261 ppm, with an average of 228 ppm (n=4). Specifically, this granitoid has high LREE concentration that ranging from 190 to 234 ppm (average=204; n=4), while the HREE concentration ranges from 12-30 ppm. Sarolangun granitoid, in other cases, the REE concentration reaches 330 ppm, with 310 ppm in LREE concentration and 20 ppm in HREE concentration (Table 3).

Table 3. The trace element compositions data from all granitoid samples.

Granitoid	Tanjungjabung Barat					Sarolangun							
Sample	TJB1	TJB2A	TJB2B	TJB3	TJB4	SR1A	SR1B	SR2	SR3	SR6	SR7	SR4	SR5
Li	-	56.7	40.9	42.6	53.6	38.9	16.4	-	-	-	-	-	-
V	30	23.3	60.7	15.6	20.1	39.8	23.3	58	-	54	-	99	59
Ga	21	17.9	16.2	16.1	17.4	18.3	8.04	24	22	16	21	23	32
Zr	-	62	83	-	-	393	-	597	779	318	483	503	451
Rb	354	290	193	248	259	221	54	224	252	214	190	233	272
Sr	-	88.64	106.20	84.54	112.9	399.0	33.70	348	328	298	411	340	506
Y	-	42.65	9.85	33.30	39.71	22.61	3.66	41	32	-	-	37	-
Nb	23	24.20	15.03	18.81	20.47	27.27	6.33	36	59	36	43	51	51
Cs	-	14.50	11.76	9.66	11.20	8.30	3.78	-	-	-	-	-	-
Ba	254	337.3	580.9	369.2	410.6	1296	212.9	917	892	1100	1270	1220	1700
Ta	-	1.83	1.84	1.84	1.84	1.84	1.84	-	-	-	-	-	-
Pb	-	46.26	27.32	44.43	61.10	36.08	17.48	-	-	-	-	-	-
Th	-	44.62	20.11	38.97	38.96	23.86	5.75	-	-	-	-	-	-
U	-	13.26	1.76	8.20	8.72	4.35	0.95	-	-	-	-	-	-
La	70	40.95	42.67	38.11	51.25	80.00	16.75	136	84	66	84	60	82
Ce	-	94.08	98.56	104.80	116.90	155.20	35.01	168	-	94	-	129	
Pr	-	9.37	9.66	9.50	11.82	14.42	3.82	-	-	-	-	-	-
Nd	-	35.5	35.4	36.1	43.2	49.1	14.6	89	-	57	-	-	-
Sm	-	8.59	7.04	8.35	9.28	8.82	2.80	-	-	-	-	-	-
Eu	-	1.07	1.47	1.22	1.23	2.51	0.57	-	-	-	-	-	-
Gd	-	8.80	5.97	8.00	9.05	7.94	2.30	-	-	-	-	-	-
Tb	-	1.35	0.69	1.19	1.30	0.95	0.29	-	-	-	-	-	-
Dy	-	7.99	2.81	6.54	7.26	4.53	1.09	-	-	-	-	-	-
Ho	-	1.55	0.44	1.28	1.40	0.91	0.18	-	-	-	-	-	-
Er	-	4.61	1.00	3.84	4.11	2.61	0.32	-	-	-	-	-	-
Tm	-	0.64	0.13	0.56	0.57	0.39	0.06	-	-	-	-	-	-
Yb	-	4.14	0.62	3.37	3.47	2.22	0.17	-	-	-	-	-	-
Lu	-	0.58	0.11	0.49	0.49	0.36	0.05	-	-	-	-	-	-
ΣLREE		190	195	198	234	310	74						
ΣHREE		30	12	25	28	20	4						
ΣREE		219	207	223	261	330	78						
$(La/Yb)_N$		7.09	49.28	8.11	10.58	25.80	69.37						
Nd/Th		0.80	1.76	0.93	1.11	2.06	2.54						
Ce/Pb		2.03	3.61	2.36	1.91	4.30	2.00						
Nb/U		1.83	8.55	2.29	2.35	6.26	6.67						

LILE (*Large-ion lithophile elements*)
HFSE (*High field-strength elements*)
LREE (*Light rare-earth elements*)
HREE
XRF data
ICP-MS data
$(La/Yb)_N$ = ratio of the chondrite normalized value

The A-type granitoids and affinities

Based on plots between total alkali (Na_2O+K_2O) and SiO_2 (Figure 11; Cox et al., 1979 in Wilson, 1989), the Tanjungjabung Barat granitoids are classified as granite and alkali granite with the alkalic magma series, with the TJB1 and TJB2B samples showing sub-alkalic magma character. Meanwhile, Sarolangun granitoids are classified into alkali granodiorite. Sarolangun granitoids have alkalic magma series character. The magmatic series based on the total alkali (Cox et al., 1979 in Wilson, 1989) are very important to be determined due to the next granite discrimination (Whalen et al., 1987) depends on the magmatic series.

For the granite discrimination, diagram proposed by Whalen et al. (1987) are used as an initial step to discriminate A-type granite with other types (I-, S-, and M-type). The background of the diagram are based on the geochemical characteristic of A-type granitoids that are commonly high in HFSE, REE, total alkali, and FeO^{tot} (Collins et al., 1982; White and Chappel, 1983; Whalen et al., 1987). As the result, this study uses cross plot between Ga/Al and the ratio of FeO_{tot}/MgO, Na_2O+K_2O, K_2O/MgO, and $(Na_2O+K_2O)/CaO$, as well as plot of Ga/Al to trace elements, such as Ce, Zn, and Nb (Figure 12; Whalen et al., 1987). Our study also use several literature data for a comparison of A-type granite in other areas in Indonesia, such as Sarudik granitoid (Zhang et al., 2020), Karimun granitoid (Irzon, 2017), and Sibolga granitoid (Setiawan et al., 2017).

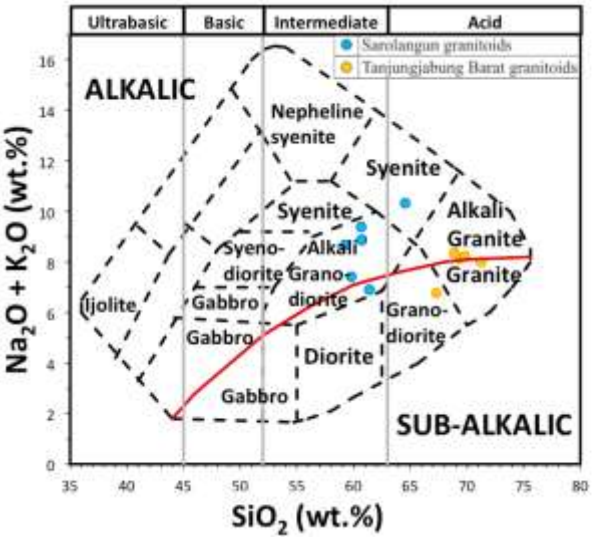

Figure 11. Granite classification based on total alkali and SiO_2 concentrations (Cox et al., 1979 in Wilson, 1989). Sarolangun granitoids are classified as alkali granodiorit, while Tanjungjabung Barat granitoids are classified as alkali granite. Both of the granitoids have alkalic affinities.

These diagrams (Figure 12) shows that Tanjungjabung Barat and Sarolangun granitoid shows the characteristic of A-type granites, together with another A-type granitoids in Indonesia. However, some samples of Tanjungjabung Barat and Sarolangun granitoid plot are overlaps with the A-type granite and other types. Such condition are usually found on the granite with sub-alkalic affinities (Whalen et al., 1987). Apart from the diagrams, the two granitoids have anomolous high of REE concentrations and highly ferroan (Frost and Frost, 2011) that are typical for the A-type granite characteristic (Collins et al., 1982).

The A-type granite then divided by Eby (1992) into A1- and A2-type granite. The A1-type has a similiar characteristic to oceanic island basalt that are typical for rifting and mantle plume environment (Eby, 1992). The A2-type granite has a similiar characteristic to island arc basalt, which occurred in vary tectonic environment from post-collision to island arc magmatism (Eby, 1992). The granitoid of Tanjungjabung Barat shows the character of A2-type granite (Figure 13). However, Sarolangun granitoid shows the different character with the character of A1-type granite (Figure 13). Despite the tectonic setting, the classification also depends on further petrogenetic processes of magma, such as assimilation and magma mixing (Eby, 1992).

The affinities of A-type granitoids also play important things for petrogenetic studies, especially for the determination of magma origins and tectonic settings (Frost and Frost, 2011). The Tanjungjabung Barat and Sarolangun granitoids shows the shoshonitic series characteristic that are enriched with K_2O (Figure 14a; Pecerillo and Taylor, 1976 in Gill, 2010). In addition, both of the granites have high Fe-index ($(FeO_{total}/(FeO_{total}+MgO))$; Figure 14b; Frost et al., 2001) which shows characteristic of ferroan granitoids (Whalen et al., 1987; Frost and Frost, 2011). The Fe-index confirmed that both granitoids have A-type character due to 97% of A-type granites observed by Frost et al. (2001) were ferroan. This character also could provide information of magma origin.

Our studies also use the modified alkali-lime index (MALI; Na_2O+K_2O-CaO; Frost et al., 2001) that are plotted against SiO_2. All of the Tanjungjabung Barat granitoids show alkali-calcic affinities (Figure 15a). Sarolangun granitoid shows an alkalic to alkali-calcic affinites (Figure 15b). Another parameter that we used is aluminium saturation index (ASI). All of the granitoid sample have ASI values more than 1 ranging from 1.03 to 2.11, in other words all samples are peraluminous (Figure 15b). The high alumina content are indicated by the mineral content of Sarolangun and Tanjungjabung Barat granitoids. The ASI that have range 1-1.14 are indicated by biotite associated with hornblende and titanite (Zen, 1988). Biotite that formed in the final stages of differentiation will show higher Al (Deer et al., 2013). The SR6 sample has ASI values 1.03. Low values of ASI could be observed in the euhedral and large crystal biotite, which indicates that biotite was formed earlier (Deer et al., 2013). High ASI values are indicated by the presence of biotite minerals associated with muscovite and sericite minerals (Zen, 1988) that could be seen in the SR1B sample. The sample shows the subhedral-anhedral biotite mineral accompanied by high amount of muscovite and sericite mineral content resulting the ASI reaches 2.11.

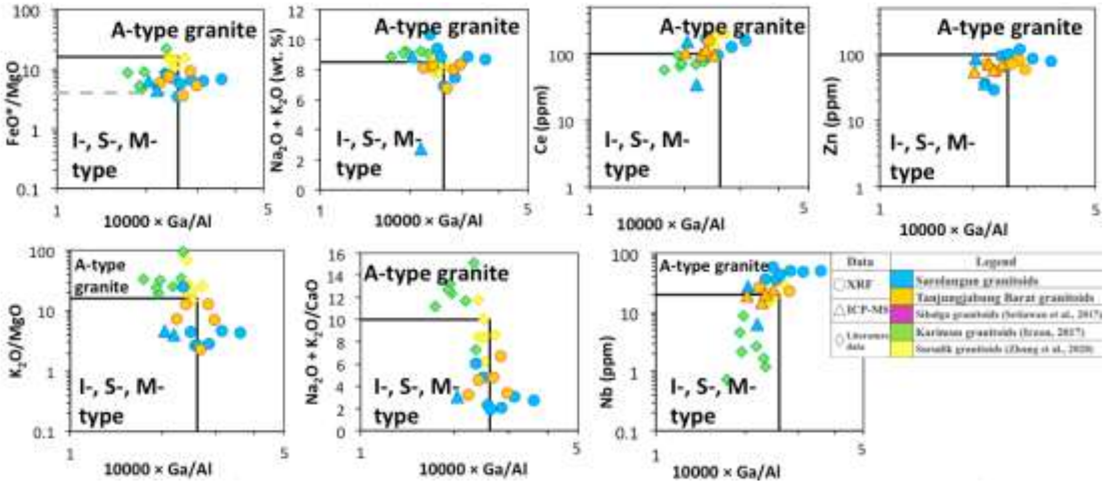

Figure 12. Cross plot between HFSE, REE, and some selected major element parameters (Whalen et al., 1987). It could be observed that Sarolangun granitoid and Tanjungjabung Barat granitoid are A-type granitoids that are more enriched with HFSE and REE.

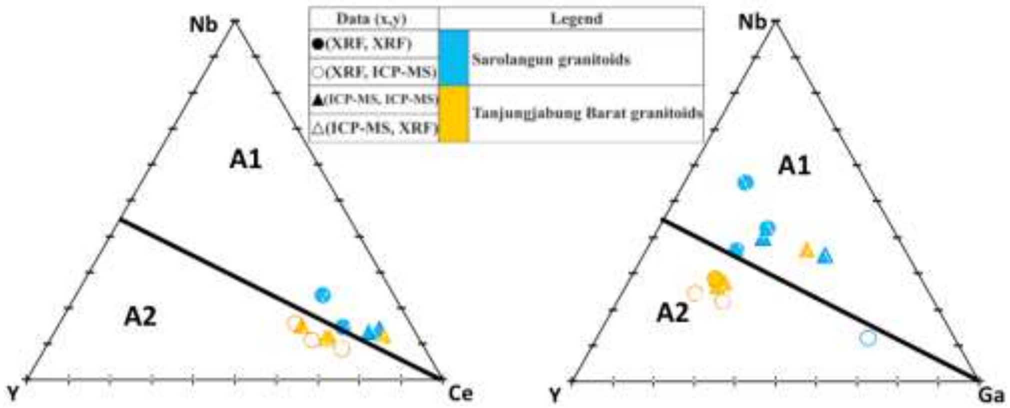

Figure 13. Ternary plot proposed by Eby (1992). Sarolangun granitoid have A1-type granitoid character that reflects oceanic island basalt character. In the other hands, Tanjungjabung Barat granitoid have A2-type granitoid character that reflects island arc basalt character. Two contrasting tectonic environment in the same area could be a result of petrogenetic processes.

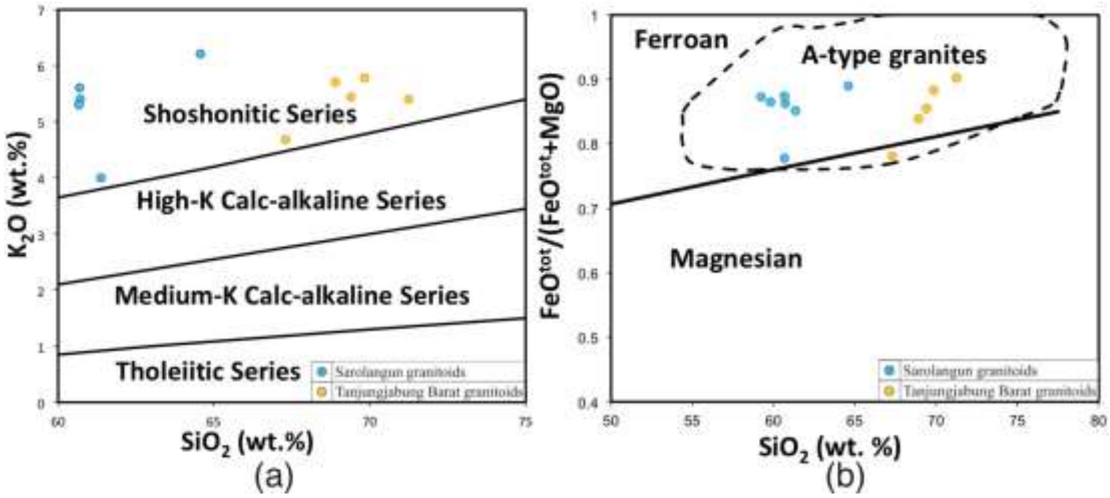

Figure 14. a) Cross plot between K_2O and SiO_2 (Pecerillo dan Taylor, 1976 in Gill, 2010) showing that both granitoids have shoshonitic affinities; b) Cross plot between Fe-index and SiO_2 (Frost et al., 2001) showing that both granitoid are ferroan granitoids that are typical for A-type granite.

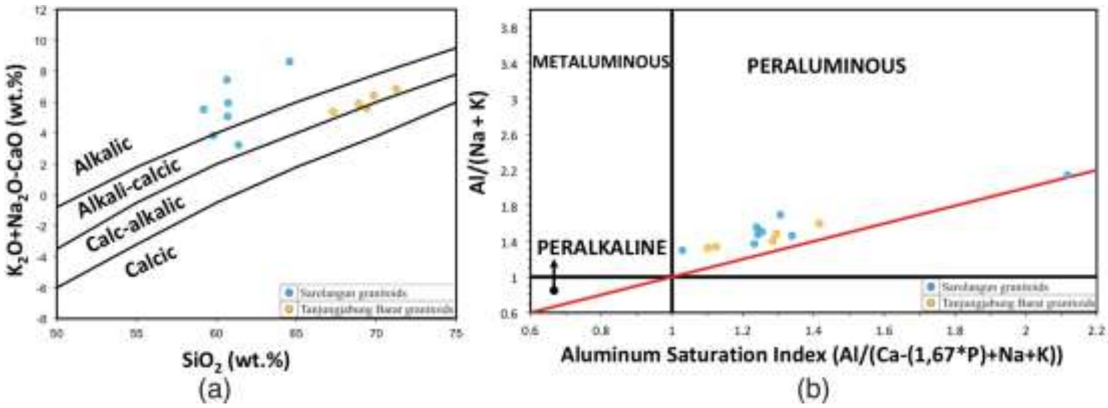

Figure 15. a) Cross plot between MALI and SiO_2 (Frost et al., 2001) showing that Tanjungjabung Barat have alkali-calcic affinites. Sarolangun granitoid shows different character having alkalic series; b) Alumina saturation index diagram (adapted from Shand, 1943 in Frost et al., 2001) showing that both granitoid have peraluminous characters.

Magma Origins

The magma source of A-type granitoids have been discussed by several researcher, from the mantle plume (anorogenic; Loiselle and Wones, 1979 in Frost and Frost, 2011; Eby, 1992), differentiation of basalt (Eby, 1992; Barbarin, 1999; Frost and Frost, 2011), and crustal melting (Barbarin, 1999; Frost and Frost, 2011). However, as we discussed earlier, the affinities of Tanjungjabung Barat and Sarolangun granitoid samples have ferroan and peraluminous characteristic. The consequences of these affinities are that both of the granitoids are formed from the melting of quartzofeldspathic crust which can be accompanied by a basaltic component or not (Frost and Frost, 2011). The high and restricted range of SiO_2 on both granitoids also suggest that the magma derived from crust (Chappel and White, 2001). It is hardly to found high SiO_2 concentration (>65%) from magma that derived from mantle, unless the magma undergo extreme fractionation.

The high content of LIL elements such as Ba and Rb could also indicate a dominant crust component because LIL elements are easily carried away from the mantle and then concentrated in the continental crust (Winter, 2001). All of the granitoid have Nd/Th ratio index ranging from 0.80-2.54 which indicates that the magma derived from crustal melting (Bea et al., 2001 in Zhang et al., 2020). In addition, the Ce/Pb ratio ranges from 1.91-4.30, and also have Nb/U ratio with a value of 1.83-8.54 that also reflects the composition of the continental crust (Hofmann et al., 1986 in Zhang et al., 2020). The trace element geochemistry supports that both of granitoids originated from crustal melting.

Magma Conditions

The chondrite-normalized REE spider diagram (Figure 16; Sun and McDonough, 1989) of Tanjungjabung Barat granitoid shows a slight negative europium (Eu) anomaly which possibly indicates reductive magma conditions. Europium tend to be divalent (present as Eu^{2+}) so it will substitute Ca^{2+} in plagioclase (Henderson, 1984). Consequently, the Eu anomaly could indicates plagioclase fractionation in the early differentiation. In contrast, Sarolangun granitoids have flat Eu pattern (no anomaly) suggesting that the Eu present as Eu^{3+} (Henderson, 1984). This indicates a more oxidative condition of the magma. Oxidative conditions means that the magma has a high oxygen fugacity. This is also consistent with the rim texture, clinopyroxene rimmed by hornblende and ilmenite rimmed by titanite, found in the Sarolangun granitoid sample (Barink, 1984; Rene, 2008). This condition not follow the original general character of typical A-type granite because A-type granite are considered formed under magma with low oxygen fugacity (Loiselle and Wones, 1979 in Frost et al., 2001).

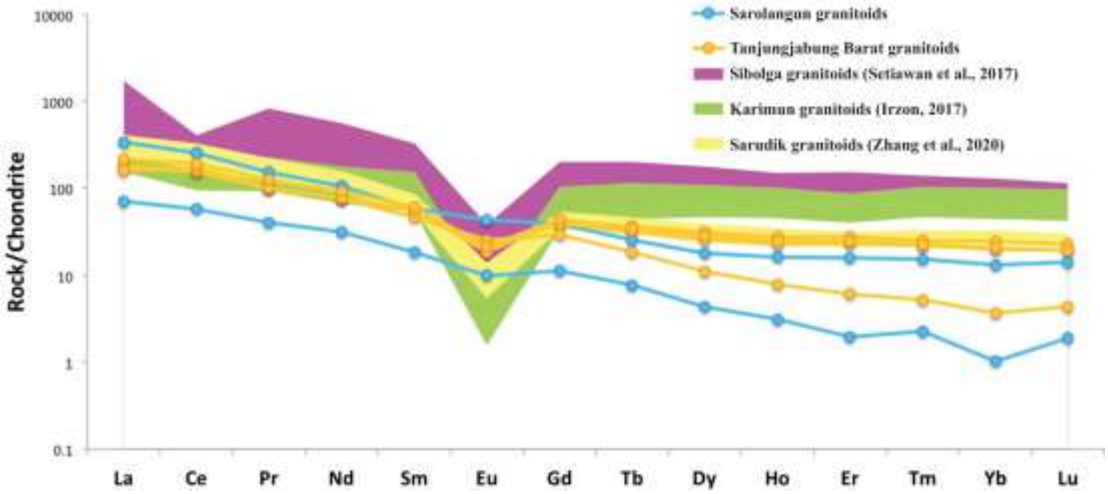

Figure 16. The chondrite-normalized REE spider diagram (Sun and McDonough, 1989).

Crystal Fractionation

Selected major elements are plotted against SiO_2 on harker variation diagram are given in Figure 17. All of the granitoid sample shows decreasing pattern in MgO, Fe_2O_3, CaO Al_2O_3, TiO_2, P_2O_5 with increasing SiO_2. In contrast, the concentration of Na_2O and K_2O tend to increase with increasing SiO_2 content (magma differentiation). The decreasing content of MgO, Fe_2O_3, CaO with increasing SiO_2 are related to the fractionation of mafic mineral (Wilson, 1989). Sarolangun granitoid shows a higher MgO, Fe_2O_3, CaO compared to Tanjungjabung Barat granitoids which confirmed by the petrographic results of Sarolangun granitoid that have more mafic mineral. The decreasing pattern in the Al_2O_3

concentration is related to the plagioclase mineral fractionation (Wilson, 1989), while the decrease of TiO_2 concentration with the increasing SiO_2 content was related to the Fe-Ti oxide mineral fractionation (Figure 17; Wilson, 1989). The decreasing content of P_2O_5 is related to the fractionation of monazite and apatite (Figure 17; Wilson, 1989). The P_2O_5 content of Sarolangun is higher than the Tanjungjabung Barat granitoid that corresponds to the petrographic analysis that showing higher abundance of monazite and apatite in Sarolangun granitoid.

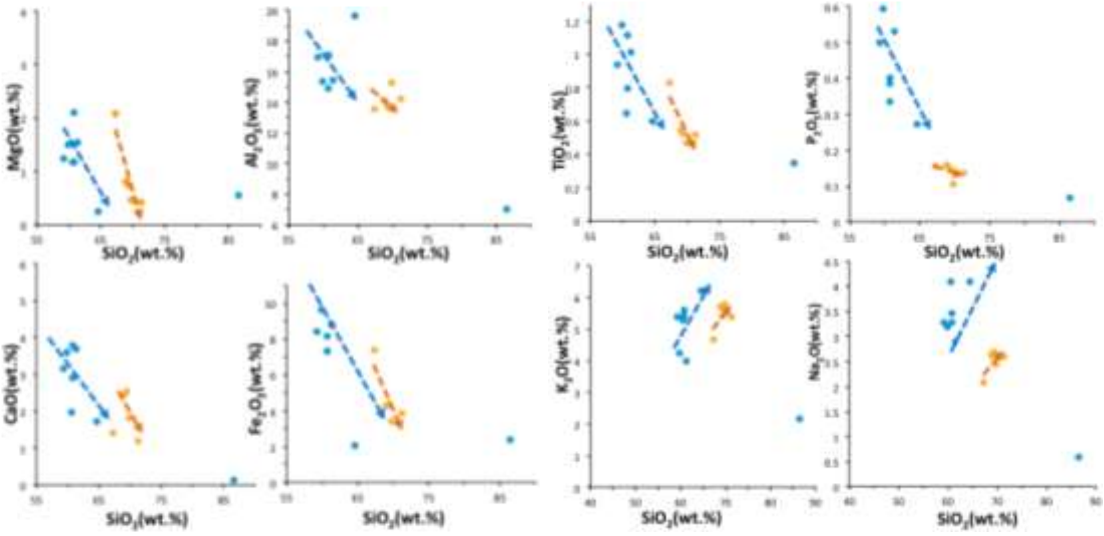

Figure 17. Harker diagram with selected major element parameters showing the crystal fractionation of the granitic magmas.

Magma Mixing

Other petrogenetic processes besides crystal fractionation that also very important is the occurence of magma mixing. Major element geochemistry data of Sarolangun granitoid, which is younger than Tanjungjabung Barat granitoids, have more mafic component (lower SiO_2 concentrations and high concentration of $Fe_2O_3^{(total)}$, CaO, MgO, and TiO_2) compared to Tanjungjabung Barat granitoids. Normally, the younger granitoid tend to have low mafic and high silica component (Gill, 2010). Therefore, with the abnormal condition, we suggest that the condition could be the result of more mafic magma involvement to the granitoids (magma mixing).

The relative “gentle” pattern of chondrite-normalized REE spider diagram (Figure 16; Sun and McDonough, 1989) of Sarolangun granitoid suggest that the LREE are more fractionated compared to the HREE. This gentle pattern of Sarolangun granitoid is represented by $(La/Yb)_N$ ratio ranging from 25.80 to 69.37 (Table 3) that relatively higher compared to the Tanjungjabung granitoid with a lower $(La/Yb)_N$ ratio ranging from 7.09-49.28 (Table 3). This high $(La/Yb)_N$ values is a typical for mantle origin (Gill, 2010) that also support the occurrence of mafic magma mixing to Sarolangun granitoid.

Tectonic Model

The Mesozoic tectonic model for Pegunungan Tigapuluh and Duabelas Mountain are interpreted from our petrological and geochemical data that have been discussed on the previous sections. The model then constrained with previous geological studies, especially tectonic reconstruction in Sumatra (Katili, 1989; McCourt et al., 1996; Barber et al., 2005; Hutchison, 2014). It has been a long discussion if the tectonic environment of A-type granite are originally related to anorogenic environment (White and Chappell, 1983; Clemens et al., 1986). However, studies conducted by Eby (1992) suggest that the A-type granite could be formed on various tectonic environment so the A-type granite are divided into A1-type and A2-type granitoids. Our study shows that Tanjungjabung Barat granitoids have A2-type characters (Figure 13) that are typical on post-collisional environment. In contrast, Sarolangun granitoids have A1-type character (Figure 13) that indicates mantle plume or rifting environment. Two very contrasting tectonic environments reflected by two different batholiths that are in the same area, Jambi, are most likely never happened. Therefore, the tectonic environment is not determined by single parameter that Eby (1992) proposed.

Another parameters that we used for tectonic discrimination are the crossplot between HFSE and LILE (Figure 18; Pearce et al., 1984; Pearce, 1996) based on the Rb, Nb, and Y concentrations. It could be seen that the Tanjungjabung Barat and Sarolangun granitoid formed in the post-collision tectonic environment (Figure 18). This is also corresponds to shoshonitic series affinities that are reflected by both granitoids (Figure 14a). According to Gill (2010), shoshonitic granitoids are commonly found on several tectonic settings such as continental rifting that are related with high-K volcanic arc. Another tectonic settings are post-collisional environment that characterized by the transformation of collisional (compressional regime) to extensional environment that are controlled by crustal thinning.

With the additional information from Pearce diagram (Pearce, 1996) and shoshonitic series, the environment of the granitoids are post-collisional. Consequently, the granitoids will have A2-type granitoid characters (Eby, 1992) like the Tanjungjabung Barat granitoid. The A1-type granitoid character of Sarolangun granitoid possibly due to the petrogenetic processes (Eby, 1992) that shift the magma character to more mantle (A1-type) character. As we mentioned earlier, the mafic magma mixing is the reason of A1-type character of granitoids.

More geochemical parameters for tectonic reconstruction are provided in this paper. Both granitoids shows ferroan affinites that indicates the granitoids are derived from reduced and anhydrous magma either from crystal fractionation or partial melting. Such condition commonly occurred in extensional environments (post-collisional), due to the magma is generally hotter and tends to undergo extensive fractionation towards Fe enrichment (Frost et al., 2001).

The trace element behavior on normalized primitive mantle spider diagram also used for tectonic reconstruction. It could be seen that all samples, in general, show almost the same pattern (Figure 19). The positive anomalies in Rb, Th, U, and Pb are observed. The positive Th, U, and Pb anomalies indicate effective crustal contamination at the time of granitoid formation (Mishra, 2011). The negative anomalies in Ba, Nb, Ta, and Ti are observed (Figure 19). The negative anomaly of Nb and Ta could indicate the occurrence of subduction fluid (Li, et al., 2019) or also a

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trace of subduction zone in magma formation (Figure 19).

The proposed tectonic model for Mesozoic Sumatra Main Range is based on geochemical and petrological data that is presented in Figure 20. The model is constrained with previous geological studies (Katili, 1989; McCourt et al., 1996; Barber et al., 2005; Hutchison, 2014). In the Late Permian to Early Triassic, the Sibumasu Block collided with the East Malaya (Indochina) Block (Figure 20a; McCourt et al., 1996; Barber et al., 2005; Hutchison, 2014) resulting in crustal thickening of the Sibumasu Block. The I-type and S-type granitoid magmatism along the East Malaya Block also occurred in this episode, which commonly referred to as Episode B (McCourt et al., 1996). The collision event is coeval with the Meso-Tethys subduction to West Sumatra Block (Katili, 1989; McCourt et al., 1996) forming I-type granitoids magmatism along the western part of West Sumatra Block.

Next, in the Late Triassic to Early Jurassic, or commonly referred as Episode B1 (McCourt et al., 1996), the thickening crust of Sibumasu Block started to melt producing magma (Figure 20b) with high and restricted SiO_2 content (Chappell and White, 2001). The subduction roll-back of Meso-Tethys occurred in this episode (Katili, 1989) triggers the extensional features (Figure 20b; Barber et al., 2005) on the zone between West Sumatra Block and Sibumasu Block. The extensional regime provides the pathway for the granitic magma intrusions that are derived from crustal melting. Moreover, the extensional regimes make the crustal contamination more effective (Clemens et al., 1986) so the granitic magma tends to have A-type granite character that is more enriched with K_2O, Na_2O, HFSE, and REE (Whalen et al., 1987; Eby, 1992; Frost and Frost, 2011). Then, the magma, that has more mantle character, derived from the Meso-Tethys subduction also moves upwards due to the buoyancy. The mafic magma then mixed onto the granitic magma formed in the West Sumatra Block (Figure 20b). Latter, the magma derived from crustal melting and undergoes magma mixing on the West Sumatra Block forms Sarolangun granitoid (Figure 20b). In another block, another magma derived from crustal melting forms Tanjungjabung Barat granitoid in Sibumasu Block (Figure 20b).

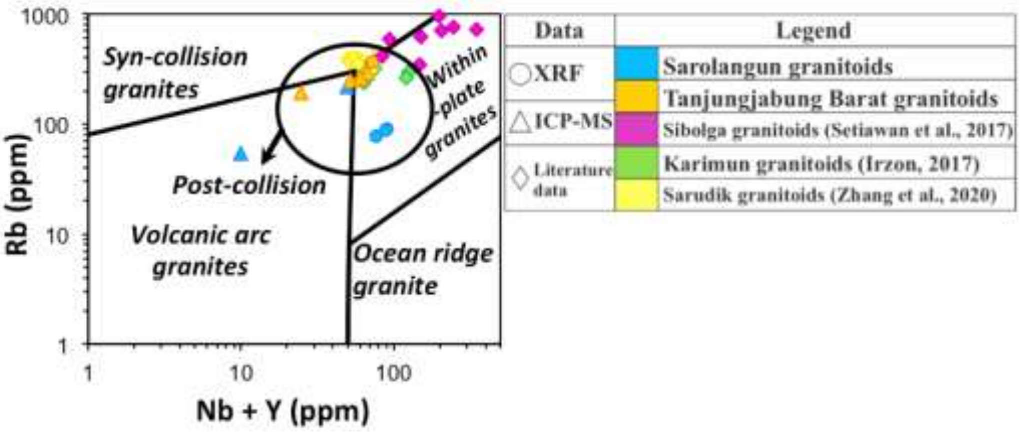

Figure 18. Cross plot between Rb and Nb+Y (Pearce, 1984; 1996). It could be observed that all of the granitoids are derived from post-collision environment.

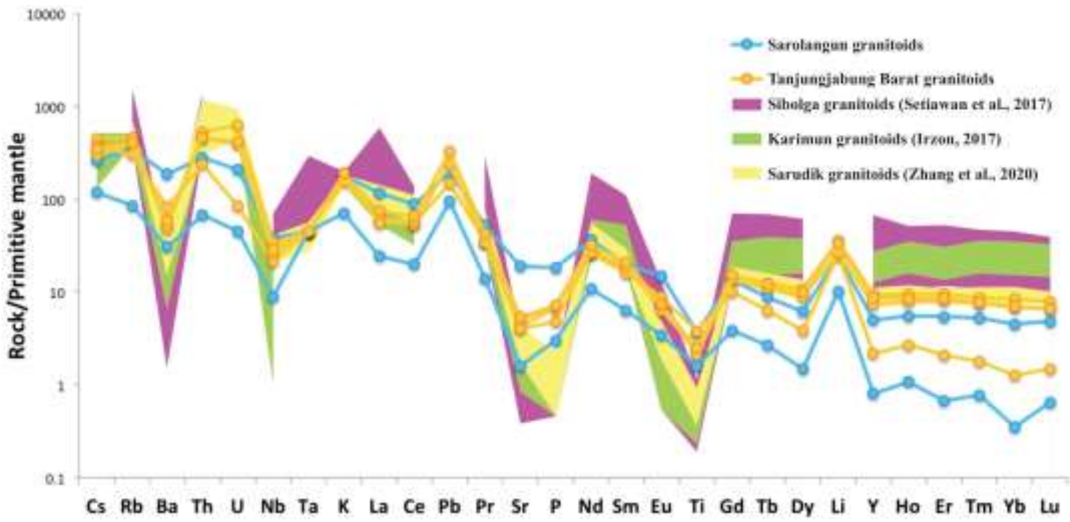

Figure 19: The primitive mantle-normalized extended spider diagram (Sun and McDonough, 1989).

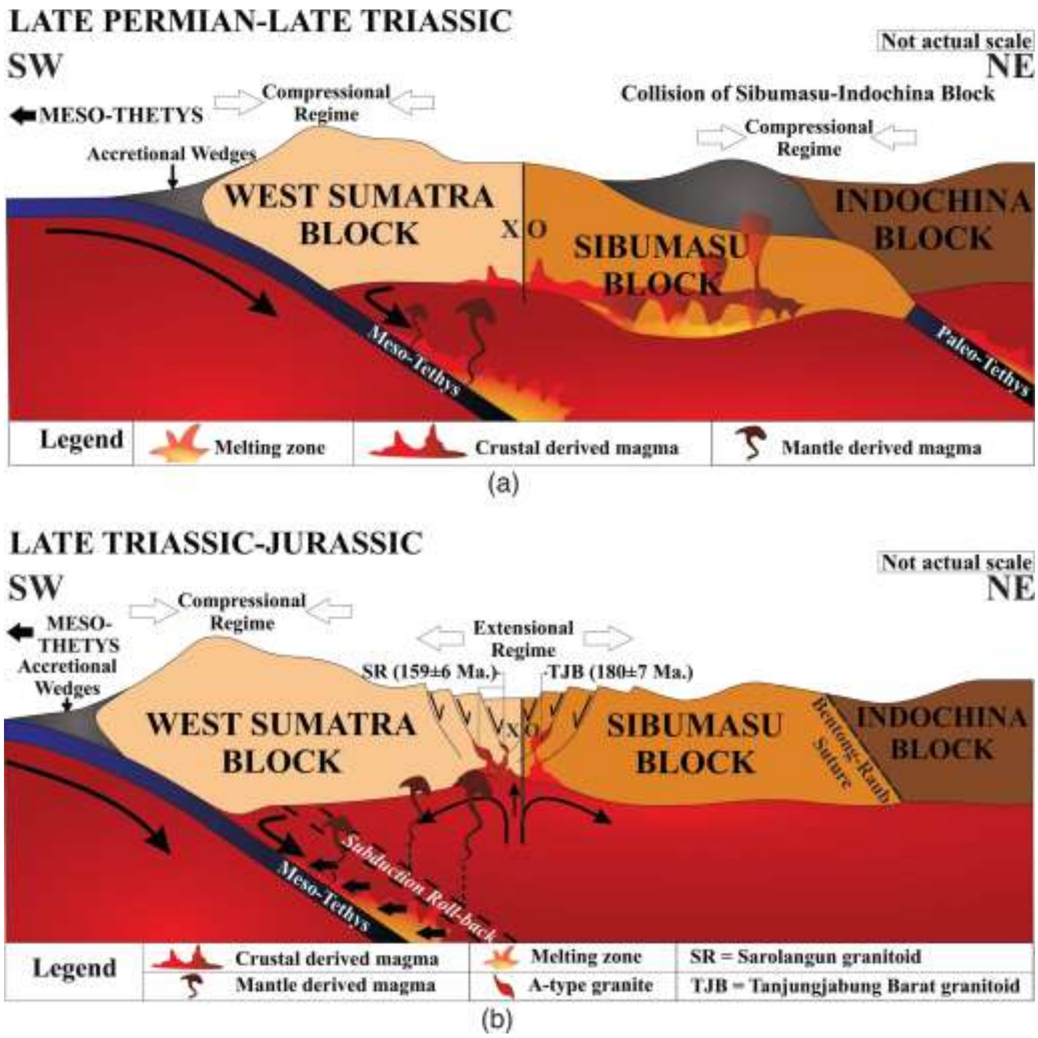

Figure 20. Proposed tectonic model for Sumatra Main Range based on combination of geochemical and petrological data, and constrained with previous geological studies (Katili, 1989; McCourt et al., 1996; Barber et al., 2005; Hutchison, 2014). A) Late Permian-Late Triassic Episode showing syn-collisional event of Sibumasu Block and Indochina Block; and B) Late Triassic-Jurassic Episodes showing the occurence of extensional regime on the middle of Sibumasu and West Sumatra Block.

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Implication for Sumatra Tectonic Reconstruction

Our model corresponds to the previous study that shows the occurrence of extensional features on the Sumatra Main Range in the Triassic to Jurassic age (McCourt et al., 1996; Barber et al., 2005). Recent studies also suggest the occurrence of A-type granite with similar affinities and Mesozoic age in the Sibolga Complex, North Sumatra (Setiawan et al., 2017; Zhang et al., 2020) and Bukit Batu, South Sumatra (Destrayuda, 2015). The other authors also pointed out that the A-type granitoid on the area mentioned above are derived from the post-collisional environment. Since our research area is situated between other A-type granitoid, therefore, possible Mesozoic rifting zone and A-type granite belt could be inferred in the Sumatra Main Range (Figure 21). This is very important for the potential of REE sources.

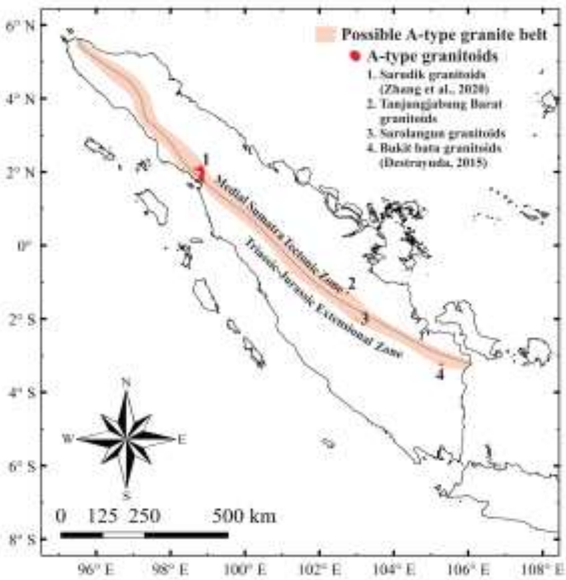

Figure 21. Proposed the possible occurence of Triassic and Jurassic extensional zone that could triggered the A-type granite formation along the belt. The line are based on interpolation from the A-type granitoid in Sarudik, North Sumatra (1; Zhang et al., 2020) and Bukit Batu, South Sumatra (2; Destrayuda, 2015). The line also follows the MSTZ zone with the assumption if the rifting occured along MSTZ zone.

Implication for REE Exploration

The tectonic settings on Triassic-Jurassic accommodate the granitic magma to be enriched with REE that very important for future REE exploration. High REE concentrations of this A-type granitoids is reflected by the high abundance of accessory minerals. Based on the petrographical analysis, REE-bearing mineral such as monazite, allanite, titanite, zircon, and apatite are abundant on both granitoid. Sarolangun granitoid tend to have higher REE mineral abundances compared to Tanjungjabung granitoid. This condition explains the higher REE concentration of Sarolangun granitoid compared to Tanjungjabung Barat granitoid.

For the economic viability, REE (LREE and HREE) concentrations of both granitoid are compared to the concentrations from other types of granitoids in Indonesia and also another A-type granitoid around the world. The comparation is well visualized in Figure 22. The REE content of both A-type granitoids are far higher (Figure 22a) compared to I-type granitoid from Muarasipongi and Kotanopan, North Sumatra (Setiawan et al., 2017) and M-type granite from Karangsambung, Central Java (Ansori et al., 2019). This is not surprising information due to the A-type granitoid should be enriched with REE (Whalen et al., 1987; Eby, 1992). Sarolangun granitoid has almost similar REE content with Sarudik A-type granitoid, North Sumatra (Figure 22a; Zhang et al., 2020). In other areas, Tanjungjabung Barat granitoid tend to have a similar REE concentration with Karimun Island A-type granitoid, Riau (Figure 22a; Irzon, 2017). Moreover, Sarolangun and Tanjungjabung Barat granitoid are relatively more enriched with REE, especially with LREE, compared to the fractionated S-type granitoid in Bangka

(Figure 22a; Ng et al., 2017). This gives some “fresh air” to REE exploration because of the fractionated S-type granitoid in Bangka are believed to be the source of REE placer deposits in Bangka. Therefore, with higher REE content, Sarolangun and Tanjungjabung Barat potentially acts as source for REE placer, REE laterite, and even “paleo” placer deposits in Sumatra Main Range.

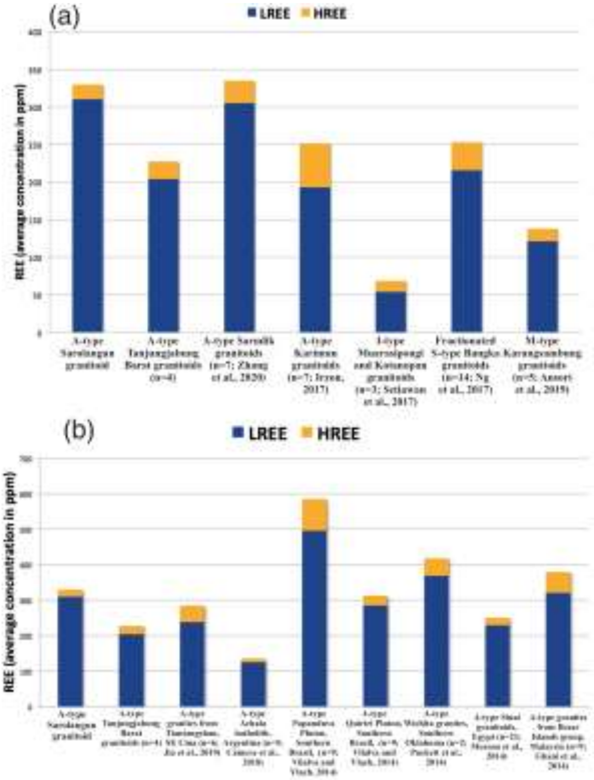

Figure 22. Economic viability of REE concentration in Sarolangun and Tanjungjabung Barat granitoids compared to a) Other types granitoid in Indonesia; and b) Other A-type granitoid from around the world.

Far from Indonesia, Sarolangun and Tanjungjabung Barat granitoid have relatively similar concentrations with other A-type granitoid around the world (Figure 22b) such as China (Jia et al., 2019), Argentina (Cámera et al., 2018), Brazil (Vilalva and Vlach, 2014), Egypt (Moreno et al., 2014), and Malaysia (Ghani et al., 2014). However, these granitoids still have lower REE concentration compared to Papanduva granitoid, Brazil (Vilalva and Vlach, 2014) and Wichita granites, Oklahoma (Puckett et al., 2018).

CONCLUSION

Tanjungjabung Barat granitoid, which represent Tigapuluh Mountains, is petrographically classified as granite *sensu stricto*. Geochemically, this granitoids are A-type granite, specifically A2-type granite. This granite has ferroan alkali-calcic peraluminous affinities that are formed in a post-collision tectonic environment accompanied by extensional features. These granitoids are formed from crustal derived magma that are rich in quartz and feldspar at low pressure. In the other hand, Sarolangun granitoid that represent Duabelas Mountains area, is also petrographically classified as granite *sensu stricto*. These granitoids also A-type granitoid but with A1-type characters. The different character of Sarolangun and Tanjungjabung Barat granitoid are the result of petrogenetic processes. This granite has an alkalic to alkali-calcic peralumine affinities that are formed in a post-collisional tectonic environment co-eval with extensional features. Based on our petrography and geochemical data, the magma source and conditions are quite similar with Tanjungjabung Barat granitoid. However, there are some indication if the magma that forms Sarolangun granitoid undergoes magma mixing with other magma that more mafic. The tectonic model proposed by our research is based petrological and geochemical data. The model is well constrained with the previous studies. The magma source of Tanjungjabung Barat and Sarolangun granitoids are quartzofeldspathic crust that are melt due to the crust thickening. This event happened due to the collision of the Sibumasu Block with the Indochina Block in Late Permian-Triassic. The tectonic regime then changed from compressional to an extensional regime due to the subduction roll-back of the Meso-Tethys in the Late Triassic-Jurassic. This event triggered the formation of a normal fault that accommodates effective crustal contamination on magma forming A-type granite character. Sarolangun granitoid magma, which is situated in the West Sumatra Block, is mixed with magma from the melting of the mantle in the subduction zone. In addition, with the recent studies showing the occurrence of A-type granitoids in North Sumatra and South Sumatra, we proposed the occurrence of A-type granitoid belt in Sumatra Main Range. Both of the A-type granitoids have relatively similar high REE concentration compared to the A-type granitoids in North Sumatra and South Sumatra. Moreover, both granitoids also have similar REE concentration with A-type granitoids from around the world. Perhaps, this study could open and improve the understanding of REE potential in Sumatra Main Range despite of in Tin Island. This study shows that Tanjungjabung Barat and Sarolangun granitoid could acts as source for REE placer, REE laterite, and even "paleo" placer deposits in Sumatra Main Range.

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REFERENCES

Ansori, C., Godang, S., Hastria, D., and Isyqi (2019) "Protolith Oceanic Island Arc dari Granitoid Tipe M dan I di Karangsambung, Kebumen, Jawa Tengah", *Jurnal Geologi dan Sumberdaya Mineral*, 20(4), pp. 249-262.

Barbarin, B. (1990), "Granitoids: main petrogenetic classifications in relation to origin and tectonic setting", *Geological Journal*, 25, pp. 227-238.

Barber, A. J., and Crow, M. J. (2005) "Pre-Tertiary stratigraphy". In: Barber, A.J., Crow, M.J., and Milsom, J., Eds., *Sumatra: Geology, resources and tectonic evolution*. Geological Society of London, pp. 175-233.

Barber, A. J., and Crow, M. J., (2009) "Structure of Sumatra and its implications for the tectonic assembly of Southeast Asia and the destruction of Paleotethys", *Island Arc*, 18(1), pp. 3-20.

Barber, A. J., Crow, M. J., and de Smet, M. E. M., (2005) "Tectonic Evolution", In: Barber, A.J., Crow, M.J., and Milsom, J., Eds., *Sumatra: Geology, resources and tectonic evolution*, Geological Society of London, pp. 234-259.

Barink, H. W., (1984) "Replacement of pyroxene by hornblende, isochemically balanced with replacement of plagioclase by garnet, in a metagabbro of upper-amphibolite grade", *Lithos*, 17, pp. 247-258.

Cámera, M. M. M., Dahlquist, J. A., Ramacciotti, C. D., Galindo, C., Basei, M. A., Zandomeni, P. S., and Grande, M. M., (2018) "The strongly peraluminous A-type granites of the Characato suite (Achala batholith), Sierras Pampeanas, Argentina: Evidence of Devonian-Carboniferous crustal reworking", *Journal of South American Earth Sciences*, 88, 551-567.

Chappel, B. W., and White, A. J. R., (2001) "Two Contrasting Granite Types: 25 years later", *Australian Journal of Earth Sciences*, 48, pp. 489-499.

Clemens, J. D., Holloway, J. R., and White, A. J. R., (1986) "Origin of an A-type granite; experimental constraints", *American Mineralogist*, 71(3-4), pp. 317-324.

Cobbing, E. J., (2005) "Granites", In: Barber, A.J., Crow, M.J., and Milsom, J., Eds., *Sumatra: Geology, resources and tectonic evolution*, Geological Society of London, pp. 54-62.

Cobbing, E. J., Pitfield, P. E. J., Darbyshire, D. P. F., and Malick, D. I. J., (1992) "The Granites of The

South-East Asian Tin Belt", *Overseas Memoir of the British Geological Survey No. 10*.

Collins, W. J., Beams, S. D., White, A. J. R., and Chappell, B. W., (1982) "Nature and origin of A-type granites with particular reference to southeastern Australia", *Contributions to mineralogy and petrology*, 80(2), pp. 189-200.

Cuney, M., (2014) "Felsic magmatism and uranium deposits", *Bull. Soc. Geol. France*, 185(2), pp. 75-92.

Destrayuda, M., (2015) *Karakteristik dan Petrogenesa Batuan Granitoid Bukit Batu, Kecamatan Pangkalampam, Kabupaten Ogan Komering Ilir, Provinsi Sumatera Selatan*, Unpublished B.Sc thesis (abstract), Gadjah Mada University, Yogyakarta.

Eby, G. N., (1992) "Chemical subdivision of the A-type granitoids: petrogenetic and tectonic implications", *Geology*, 20(7), pp. 641-644.

Frost, B. R., Barnes, C. G., Collins, W. J., Arculus, R. J., Ellis, D. J., and Frost, C. D., (2001) "A geochemical classification for granitic rocks", *Journal of petrology*, 42(11), pp. 2033-2048.

Frost, C. D., and Frost, B. R., (2011) "On ferroan (A-type) granitoids: their compositional variability and modes of origin", *Journal of petrology*, 52(1), pp. 39-53.

Ghani, A. A., Hazad, F. I., Jamil, A., Xiang, Q. L., Ismail, W. N. A.W., Chung, S. L., Lai, Y. M., Roselee, M. H., Islami, N., Nyein, K. K., Hassan, M. H. A., Bakar, M. F. A., Umor, M. R., (2014) "Permian ultrafelsic A-type granite from Besar Islands group, Johor, peninsular Malaysia", *Journal of Earth System Science*, 123(8), pp. 1857-1878.

Gill, R., (2010) *Igneous Rock and Processes: a Practical Guide*, Wiley-Blackwell, West Sussex, UK.

Henderson, P., (1984) *Rare Earth Element Geochemistry*, Elsevier Science Publishers B. V., Netherlands.

Hutchison, C. S., (2014) "Tectonic evolution of Southeast Asia", *Bulletin of the Geological Society of Malaysia*, 60, pp. 1-18.

Irzon, R., (2017) "Geochemistry of Late Triassic weak Peraluminous A-Type Karimun Granite, Karimun Regency, Riau Islands Province", *Indonesian Journal on Geoscience*, 4(1), pp. 21-37.

Jia, R. Y., Wang, G. C., Geng, L., Pang, Z. S., Jia, H. X., Zhang, Z. H., Chen, H., and Liu, Z., (2019) "Petrogenesis of the Early Cretaceous Tiantangshan A-Type Granite, Cathaysia Block, SE China: Implication for the Tin Mineralization", *Minerals*, 9(5), pp. 257.

Katili, J. A., (1989), "Geologi Indonesia", *Majalah Ikatan Ahli Geologi Indonesia*.

Li, J., Qian, Y., Li, H., Sun, J., Yang, X., Chen, B., Fan, X., Sun, F., (2019) "The Late Ordovician granitoid in the East Kunlun Orogenic Belt, Northwestern China: Petrogenesis and constraints for tectonic evolution of the Proto-Tethyan Ocean", *International Journal of The Earth Sciences*, pp. 1-23.

McCourt, W. J., Crow, M. J., Cobbing, E. J., and Amin, T. C., (1996) "Mesozoic and Cenozoic plutonic evolution of SE Asia: evidence from Sumatra, Indonesia", *Geological Society, London, Special Publications*, 106(1), pp. 321-335.

Mishra, M. K., Devi, S. J., Kaulina, T., Dass, K. C., Kumar, S., and Ahmad, T., (2011) "Petrogenesis and Tectonic Setting of the Proterozoic Mafic Magmatic Rocks of the Central Indian Tectonic Zone, Betul Area: Geochemical Constraints", In Srivastava, R. K., Ed., *Dyke Swarms: Keys for Geodynamic Interpretation*. Springer-Verlag Berlin Heidelberg, Berlin.

Moreno, J. A., Molina, J. F., Montero, P., Anbar, M. A., Scarrow, J. H., Cambeses, A., and Bea, F., (2014) "Unraveling sources of A-type magmas in juvenile continental crust: constraints from compositionally diverse Ediacaran post-collisional granitoids in the Katerina Ring Complex, southern Sinai, Egypt", *Lithos*, 192, pp. 56-85.

Ng, S. W. P., Whitehouse, M. J., Roselee, M. H., Teschner, C., Murtadha, S., Oliver, G. J. H., Ghani, A. A., and Chang, S. C., (2017) "Late Triassic granites from Bangka, Indonesia: A continuation of the Main Range granite province of the South-East Asian Tin Belt", *Journal of Asian Earth Sciences*. 138. pp. 548-561.

Pearce, J., (1996) "Sources and settings of granitic rocks", *Episodes*, 19, pp. 120-125.

Pearce, J. A., Harris, N. B. W., dan Tindle, A. G., (1984) "Trace element discrimination diagrams for the tectonic interpretation of granitic rocks", *Journal of Petrology*, 25(4), pp. 956-983.

Puckett, R. E., Hanson, R. E., Eschberger, A. M., Brueseke, M. E., Bulen, C. L., Price, J. D., (2014) "New insight into the Early Cambrian igneous and sedimentary history of the Arbuckle Mountains Area of the Southern Oklahoma Aulacogen from basement well penetration", In: Suneson, N., Ed., *Igneous and Tectonic History of the Southern Oklahoma Aulacogen*, Mewbourne College of Earth and Energy, The University of Oklahoma, pp. 61-94.

Rene, M., (2008) "Titanite-ilmenite-magnetite phase relations in amphibolites of the Chynov area (Bohemian massif, Czech Republic)", *Acta Geodynamica et Geromaterialia*, 5(3), pp. 239-247.

Schwartz, M. O., and Surjono, (1990) "Sungei Isahan - A New Primary Tin Occurrence in Sumatra", *Geological Society Malaysia*, Bulletin 26, pp. 181-188.

Schwartz, M. O., Rajah, S. S., Askury, A. K., Putthapiban, P., and Djaswadi, S., (1995) "The

Southeast Asian Tin Belt", *Earth-Science Reviews*, 38, pp. 95-293.

Setiawan, I., Takahashi, R., and Imai, A., (2017) "Petrochemistry of granitoids in Sibolga and its surrounding areas, North Sumatra, Indonesia", *Resource Geology*, 67(3), pp. 254-278.

Simandjuntak, T. O., Surono, Gafoer, S., Amin, T. C., (1991) *Peta Geologi Lembar Muarabungo, Sumatra, skala 1 : 250.000*, Pusat Penelitian dan Pengembangan Geologi, Bandung.

Sun, S. S., and McDonough, W. F., (1989) "Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes", *Geological Society*, London, Special Publications, 42(1), pp. 313-345.

Suwarna, N., Budhitrisna, T., Santosa, S., and Mangga, S.A., (1994) *Peta Geologi Lembar Rengat, Sumatra, skala 1 : 250,000*, Pusat Penelitian dan Pengembangan Geologi Bandung.

Van Gosen, B. S., Verplanck, P. L., Seal, R. R., II, Long, K. R., Gambogi, J., (2017) "Rare-earth elements. In: Schulz, K. J., DeYoung, J. H., Jr., Seal, R. R., II, Bradley, D. C., Eds., *U.S. Geological Survey Professional Paper 1802: Critical mineral resources of the United States-Economic and environmental geology and prospects for future supply*, U.S Geological Survey, Reston, Virginia.

Vilalva, F. C., and Vlach, S. R., (2014) "Geology, petrography and geochemistry of the A-type granites from the Morro Redondo Complex (PR-SC), southern Brazil, Graciosa Province", *Anais da Academia Brasileira de Ciências*, 86(1), pp. 85-116.

Whalen, J. B., Currie, K. L., and Chappell, B. W., (1987) "A-type granites: geochemical characteristics, discrimination and petrogenesis", *Contributions to mineralogy and petrology*, 95(4), pp. 407-419.

White, A. J. R., and Chappell, B. W., (1983) "Granitoid types and their distribution in the Lachlan Fold Belt, southeastern Australia" *Geological Society of America Memoir*, 159(12), pp. 21-34.

Wikarno, Suyatna, D. A. D., and Sukardi, S., (1984) "Granitoids of Sumatra and the Tin Islands", In: Hutchison, C. S., Eds., *Geology of Tin Deposits in Asia and the Pacific*. Geological Society of London, pp. 234-259.

Wilson, M., (1989) *Igneous Petrogenesis: A Global Tectonic Approach*, Springer, Netherlands.

Winter, O.D., (2001*) An Introduction to Igneous and Metamorphic Petrology*, Prentice Hall Upper Saddle, New Jersey.

Zhang, H., Hu, P., Cao, L., Tampubolon, A., Liu, A., Cheng, X., Zhan, M., Pan, L., Dai, Y., Pan, B., (2020) "Geochemical characteristics and Sr-Nd-Hf isotope compositions of Late Triassic post-collisional A-type granites in Sarudik, SW Sumatra, Indonesia", *Island Arc*, 29(1).