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RISET
Geologi dan Pertambangan

GEOCHEMICAL EVIDENCE OF ISLAND-ARC ORIGIN IN VOLCANIC ROCKS OF CENTRAL SUMATERA

Bukti Geokimia Asal Mula Busur Kepulauan dalam Batuan Volkanik di Sumatera Tengah

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ABSTRACT Geochemical study on volcanic in Lampung and Bengkulu regions proposed a preposition that the western part of Sumatera is formed by a separated fragment with island-arc character and does not belong to continental margin of Eurasia. Geochemical signatures of western and eastern volcanic in Central Sumatera have confirmed the preposition indicated by evidences of existing island-arc tectonic environment on the western volcanic and both island-arc and continental tectonic environments on the eastern volcanic. Besides that, the geochemical data in this region have revealed the third tectonic environment reflecting development of back-arc tectonic setting in the geological history of the island. The island-arc tectonic setting is marked by higher ratio of (Ti/Ce)N, varying from 0.15 to 0.3, but in narrow ratio of (Ta/Nb)N, between 1.0 to 1.5, while the Active Continental Margin tectonic environment is characterized by wide range of (Ta/Nb)N ratio, ranging from 1.2 to 2.8 but with ratio of (Ti/Ce)N less than 0.1. The back-arc basin tectonic setting is marked by high ratio of (Ti/Ce)N, up to more than 0.8. The results are made based on rock chemistry analysis including major, trace and rare earth elements.

Keywords: geochemical, volcanic, Sumatera, island-arc, continental, preposition, back-arc basin.

ABSTRAK. *Studi geokimia batuan gunungapi di wilayah Lampung dan Bengkulu telah menghasilkan sebuah preposisi yang menyatakan bahwa bagian barat pulau Sumatera dibentuk oleh sebuah fragmen yang terpisah dengan ciri busur kepulauan dan ia tidak termasuk tepian benua Eurasia. Pola geokimia batuan gunungapi di sisi barat dan timur Sumatera Tengah, telah mengkonfirmasi preposisi tersebut yang ditunjukkan oleh bukti-bukti tentang keberadaan lingkungan tektonik busur kepulauan pada batuan gunungapi di sisi barat dan kedua lingkungan tektonik busur kepulauan dan benua pada batuan gunungapi di sisi timur. Di samping itu, data geokimia wilayah ini telah mengungkap lingkungan tektonik ketiga yang mencerminkan perkembangan lingkungan tektonik busur belakang dalam sejarah geologi pulau ini. Lingkungan tektonik busur kepulauan ditandai oleh rasio (Ti/Ce)N yang tinggi, berkisar antara 0.15-0.3, tetapi dalam rasio (Ta/Nb)N yang sempit antara 1.0 dan 1.5. Sementara itu, lingkungan tektonik tepian benua aktif dicirikan oleh rasio (Ta/Nb)N yang lebar, berkisar dari 1.2 s/d 2.8, tetapi dengan rasio (Ti/Ce)N kurang dari 01. Lingkungan tektonik busur belakang ditandai oleh rasio (Ti/Ce)N yang tinggi, hingga lebih dari 0.8. Semua hasil tersebut di atas didasarkan pada analisis kimia batuan yang mencakup unsur utama, jejak dan unsur jarang.*

Kata kunci: *geokimia, volkanik, Sumatera, busur kepulauan, benua, preposisi, cekungan busur belakang*

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INTRODUCTION

Sumatera is situated in the westernmost of Indonesia region and one of developing islands among five main islands in the archipelago country. Geologically, the island is composed by different rocks, dominated by volcanic and sedimentary rocks, with different age, from Paleozoic Era to Quaternary Period. Regionally, Sumatera together with Java, Kalimantan, Sulawesi, Malaya Peninsula, Indochina, Thailand and shallow water among them (Sunda Shelf), have formed the Sundaland Block (Figure 1). This Block is believed as the Eurasia continental margin in the southeast, where the Indian Australian oceanic crust subducted oblique beneath the Sumatera (Fitch TJ., 1972; Hamilton W., 1974, 1979). Therefore, many authors classify Sumatera as continental margin of Eurasia or in other words, the island belongs to active continental margin tectonic setting (Hamilton, 1979; Curray, 1989; Barber, 2000; Barber and Crow, 2003; Crow, 2005).

From the geological history point of view, Sumatera has cropped out different rocks with various ages, from Paleozoic era to Quaternary period. The geochronological rock data lead to an understanding that the island consists of several parts of micro continents, namely Sikuleh Continental Fragment, Natal Continental Fragment, and three micro continents, such as Mergui Micro Continent, Malaka Micro Continent and East Malaya Micro Continent (Cameron et al., 1980; Pulunggono and Cameron, 1984). Along the western side, between the Sikuleh and Natal continental fragments with the Mergui Micro Continent, the Woyla Terrains (Mesozoic in age) extent from NW to SE (Figure 2). Meanwhile, the same region is recognized also to be formed by two different micro continents, known as Sibumasu and Indochina micro continents (Metcalfe, 1998).

Two above point of views confirmed that Sumatera has been formed by the continental components and belongs to active continental margin tectonic setting.

Different from the above opinions, a recent geochemical study, based on trace elements and REEs, that has been conducted on volcanic rocks along the western side of the Sumatera Island, particularly in Lampung and Bengkulu has revealed different evidences indicating the presence of strongly island-arc character in the western side of the island. It has changed gradually into continental character eastwards

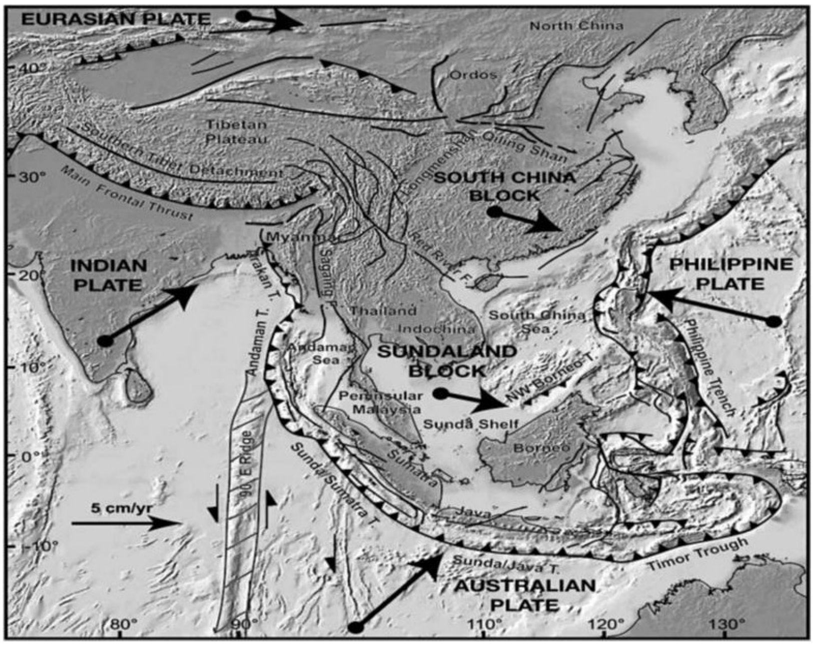

Figure 1. Sumatera as part of Sundaland Block where Australian Plate subducted beneath the island in the south (Simons et al., 2007)

and become fully continental from Sumatera Fault Zone areas to the east side of the island. The phenomenon has been recognized clearly in Lampung and Bengkulu regions. These evidences lead to a preposition that the western side component of the Sumatera consisting of Sikuleh and Natal continental fragments and Woyla Terrains should be developed in island-arc tectonic setting before it moved and collided to the continental margin of Eurasia. It means that all volcanic produced by interaction between the Indian oceanic crust and the western component of the Sumatera has to be island-arc in character.

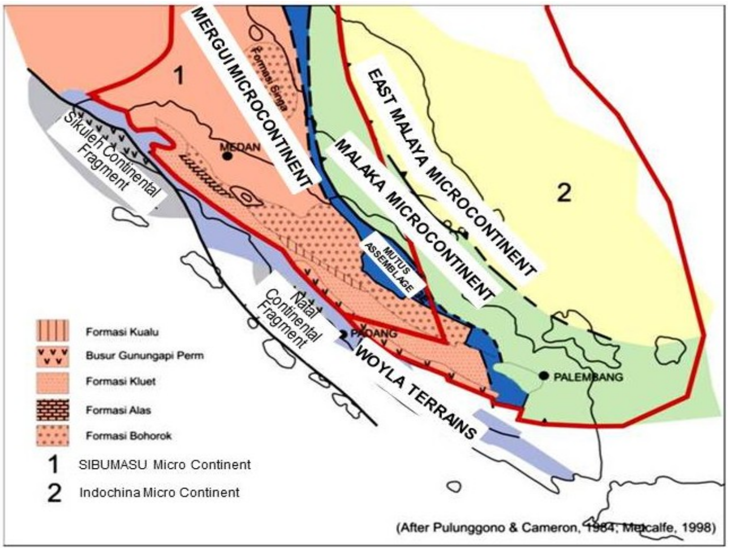

Figure 2. Tectonic map of the Sumatera and surrounding area showing micro continent components as the main components of the Sundaland Block (after Pulunggono & Cameron, 1984 and Metcalfe, 1998)

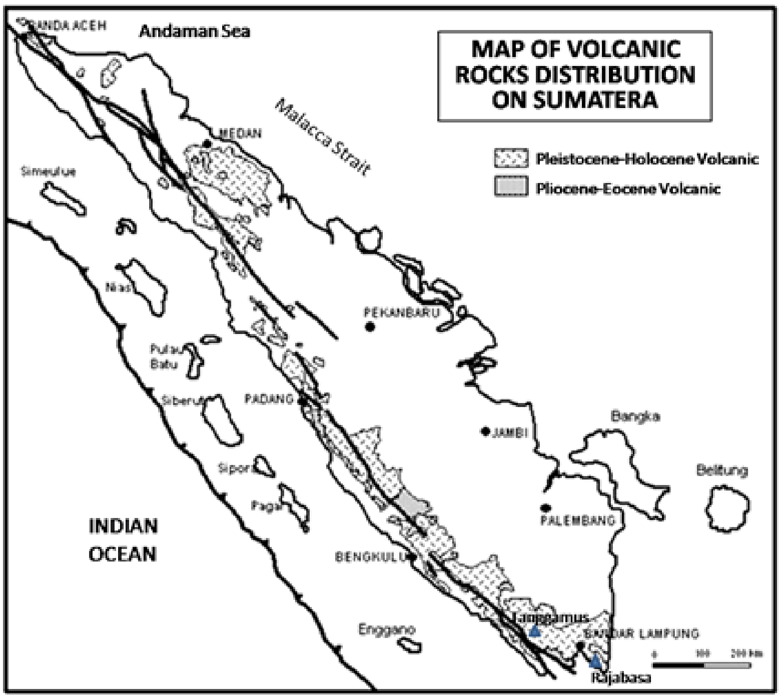

Figure 3. Distribution of volcanic on the Sumatera Island concentrated only along the western side of the island (after Zulkarnain, 2007)

As anywhere in the world, the subduction system has controlled the formation of volcanic activities as well as the volcanic chains in the western coast of the Sumatera. The volcanic age ranges from Pliocene to Holocene and the younger ones has been distributed widely along the western side of the island (Figure 3).

As mentioned above, the volcanic generated by subducting of Indian oceanic crust beneath the western component of Sumatera has to be island-arc character, so that the geochemical signatures of all volcanic along the western side of the island can be used to confirm whether the western component of the island is island-arc fragment or not. The confirmation for the above preposition is already obtained from the volcanic in Lampung (Zulkarnain, 2011) and in Bengkulu (Zulkarnain, 2012).

So, the aim of this paper is to demonstrate the geochemical signatures of volcanic in Central Sumatera in order to confirm the continuation of the island-arc character of the volcanic along the western side of Sumatera in proofing the above preposition.

SAMPLE LOCATIONS AND ANALYTICAL METHOD

Volcanic samples were collected in Painan and Muara Labuh areas representing the western volcanic and in Solok area which belongs to eastern volcanic. Due to lack of fresh rock samples from the western side, only six samples were chemically analyzed, while from the eastern volcanic there are 18 samples were analyzed. All samples were analyzed for major-, trace- and rare earth elements (REE). The analysis was done by Activation Laboratories in Canada under analysis code 4Litho. They offered a lithium metaborate/ tetraborate fusion ICP Whole Rock Package and a trace element ICP/MS package that is unique for scope of elements and detection limits. The two packages are combined in Code 4Litho and Code 4Lithoresearch.

The western side volcanic were sampled near to the coast, therefore it should represent the island-arc character, while the eastern side ones have been collected around the Sumatera Fault Zone which is expected to reflect gradually change into continental character (Figure 4).

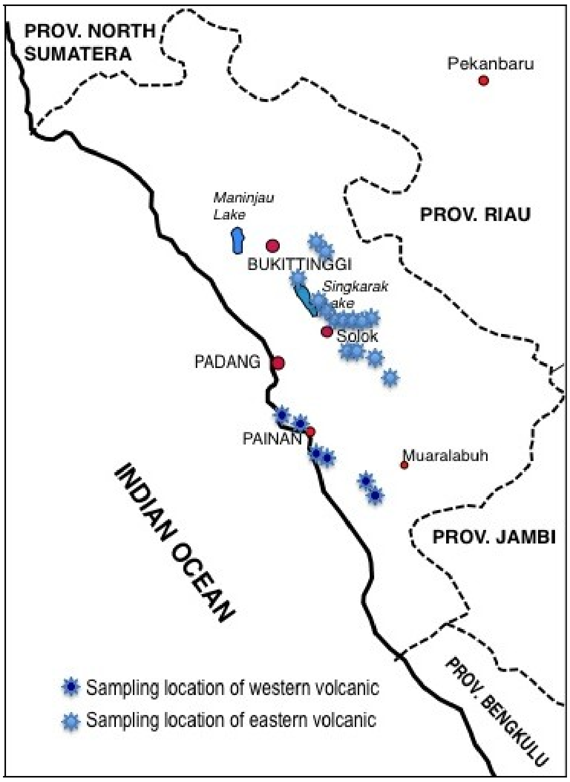

Figure 4. Sample locations map showing the location where samples of the western and eastern volcanic in Central Sumatera has collected.

ANALYTICAL RESULTS

The analytical results will be discussed separately from major elements through trace elements to REE. The samples of the western volcanic are labeled with PN (for Painan) and ML (for Muara Labuh), while the samples of eastern volcanic are labeled with SL (for Solok).

Major Elements

The analytical results of the major elements are given in the Table 1. Eighteen samples of the eastern volcanic show wide range of SiO_2 content, varying from 47.71 weight % to around 74.4 weight %. Compositionally, they range from andesitic basalt to granite or rhyolite, but most of them are andesite or dacite. The wide range of rocks composition and domination of more acidic rocks are character of the continental setting volcanic, generating in the subduction zone where oceanic crust subducted beneath continental margin. It indicates that the eastern volcanic should be derived from magma generated in the continental setting. Meanwhile, the four samples of western volcanic are very similar in composition with SiO_2 content around 51 to 55 weight %. This pattern is common in the volcanic derived from magma in the subduction system where oceanic crust subducted beneath another oceanic crust (island-arc type). Volcanic derived from magmas in the subduction system can be classified as continental and island-arc types depend on the type of the crust beneath which the oceanic crust subducted. Therefore, it is necessary to identify more detail in order to find out the character of the western volcanic.

Statistically, it is clear in the above table that among the eastern volcanic samples, there is one unusual sample containing extreme high CaO

Table 1. Analytical results of the Major Elements of western and eastern volcanic from Central Sumatera (Painan and Solok regions)(in weight %).

	SiO2	Al2O3	Fe2O3(T)	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	LOI	Total
SL 22A	63.10	16.38	4.28	0.14	0.99	3.30	4.22	3.70	0.71	0.26	1.96	99.06
SL 26	59.08	18.83	5.74	0.14	1.69	6.28	3.34	2.30	0.74	0.20	2.24	100.60
SL 28D	70.22	14.16	3.03	0.06	0.90	2.86	3.23	3.99	0.32	0.09	0.58	99.43
SL 38	60.49	17.02	6.04	0.11	2.82	6.56	2.85	2.11	0.71	0.14	1.37	100.20
SL 42	61.49	17.14	5.13	0.09	2.29	6.32	3.08	2.45	0.60	0.16	0.55	99.30
SL 43B	59.35	18.13	6.35	0.13	2.22	6.57	2.93	2.03	0.79	0.19	2.06	100.80
SL 03	74.02	13.77	1.11	0.04	0.16	0.54	4.53	4.23	0.16	0.05	0.50	99.12
SL 04	54.78	14.36	8.81	0.18	5.72	7.92	2.72	2.42	0.62	0.43	1.08	99.06
SL 05	60.31	16.70	6.62	0.20	2.89	6.22	3.33	1.77	0.51	0.28	1.16	100.00
SL 10	69.16	14.08	3.27	0.10	0.77	1.90	4.17	2.93	0.37	0.15	1.43	98.33
SL 14A	70.43	14.91	3.71	0.08	0.79	1.38	1.29	3.70	0.53	0.13	3.76	100.70
SL 15	59.02	16.50	6.28	0.15	2.63	5.95	3.08	1.83	0.62	0.16	2.26	98.48
SL 18A	59.78	18.16	5.22	0.10	2.02	6.05	3.10	1.84	0.57	0.18	2.58	99.62
SL 32	57.72	16.01	7.53	0.13	3.64	7.16	2.80	2.01	0.73	0.20	1.06	98.99
SL 35	54.26	20.94	6.84	0.10	1.67	6.52	3.03	1.55	0.73	0.24	4.84	100.70
SL 41	57.48	18.07	6.77	0.12	2.51	6.72	3.52	1.89	0.69	0.20	1.25	99.23
SL 47	47.71	13.87	7.42	0.17	8.39	18.38	0.73	0.43	0.39	0.02	1.71	99.22
SL 49B	72.42	14.05	1.80	0.05	0.23	1.22	3.07	5.91	0.18	0.06	0.56	99.54
PN 01A	53.08	18.09	9.10	0.17	3.33	8.04	3.14	1.28	0.88	0.25	2.82	100.20
PN 5A	55.31	15.92	8.28	0.25	2.96	7.16	2.72	0.67	0.90	0.25	5.02	99.45
PN 12A	51.24	21.65	7.44	0.12	2.31	9.34	3.22	0.58	0.94	0.23	2.81	99.87
PN 08B	52.82	19.00	9.42	0.16	2.92	7.31	3.54	1.12	1.03	0.30	2.04	99.65
ML 01	52.19	19.57	9.3	0.166	4	9.15	3.33	1.15	1.063	0.25	0.24	100.4
ML 07A	55.63	18.42	7.39	0.128	3.65	7.69	2.82	1.53	0.787	0.2	1.98	100.2

content, up to 18 weight % and high MgO content, up to 8.39 weight % (sample SL 47). This sample contains low Al_2O_3, about 13 weight % and extreme low Na_2O, less than 1 weight % and K_2O, less than 0.5 weight %. This sample should not be derived from magmas either in the continental environment or in the island-arc setting. It must be crystallized from magmas generated in different tectonic setting.

Plot the samples in the correlation diagram of SiO_2 versus K_2O (Le Bass et al., 1986) shows clearly that all volcanic are classified as medium-K to high-K types, while one sample is identified as shoshonitic rock (Figure 5). It is also clear that most of the eastern volcanic are andesite (SiO_2 ranging from 53 to 57 weight %) and dacitic (SiO_2 varying from 57 to 63 weight %) to rhyolite (SiO_2 more than 63 weight %), while one sample is categorized as basalt. The shoshonitic rock looks like originally to be derived from crystallized magma, because it does not show indication of metasomatism process (very low LoI and high potassium and sodium). The basalt sample (most basic one with SiO_2 around 48 weights %) is the unusual sample and it is plotted separately far away in the diagram from the others. In other side, the samples of western volcanic are distributed randomly where four samples are classified as andesite medium-K, while the other two samples are distributed along the border between Low-K and Medium-K.

As volcanic expected to be derived from the island-arc environment, the six samples of western volcanic should belong to the Low-K type, but four of them show enrichment on potassium. It is probably related to its original magma composition containing higher potassium. However, plot of all samples in the affinity diagram of SiO_2 versus FeO*/MgO (Miyashiro, 1974) confirm that almost all samples of western volcanic classify as tholeiitic rocks (only one sample lying at the border), together with a few samples of eastern volcanic, while most of the samples from eastern side belongs to calc-alkaline affinity (Figure 6). The unusual sample, although it shows basic composition, is plotted as calc-alkaline rocks and it means the sample should not come from magmas in island-arc setting.

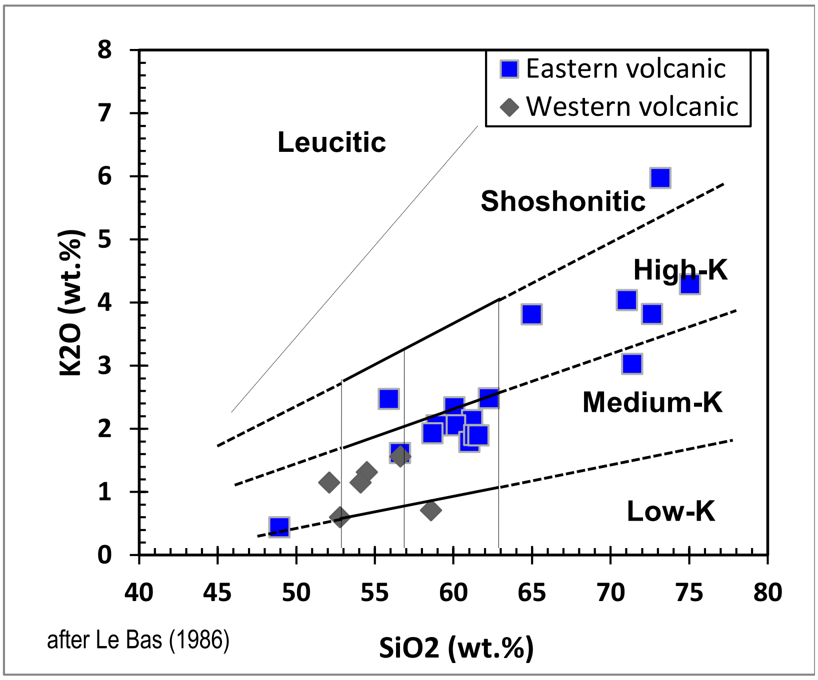

Figure 5. Plot all samples in the diagram of SiO_2 versus K_2O showing the wide composition of the eastern volcanic (after Le Bas et al., 1986)

Trace Elements

To reveal the origin tectonic setting where the rocks were formed, trace elements and REE is more powerful than major elements because the major elements are very vulnerable to changing of their environments. Geological processes in a long time can easily modify the abundance and signatures of the major elements through changing of chemical and mineralogical compositions of the rocks. In other side, trace elements and REE are more stable and not so easy to be influenced by the surrounding processes, chemically or physically, particularly the compatible elements.

All 22 samples of western and eastern volcanic in Central Sumatera were analyzed for selected trace elements and the results are shown in the Table 2. All concentration of the elements is in ppm. Table 2 shows that there are some different in concentration of certain elements between the eastern volcanic and western volcanic. The western volcanic that probably derived from island-arc tectonic setting are lower in potassium content (less than 10000 ppm, except sample PN01A) than the eastern volcanic (continental origin) having higher K, ranging from 13000 to more than 49000 ppm. The unusual sample of the eastern volcanic (SL-47) shows very low potassium content (3659ppm) and this data confirm that the rock does not belong to either continental setting or island-arc environment. Furthermore, the western volcanic are also lower in P, Rb, Th, Ta, Ce but higher in Ti and Sr than the eastern volcanic.

To get more evidences in revealing the origin of the rocks, all analytical results of the selected trace elements will be plotted in spider diagrams. For the purpose, the results have been normalized using method introduced by Pearce (1983). Plot of the western volcanic in trace elements spider diagram is demonstrated in the Figure 7. The trace elements patterns of the western volcanic show insignificant enrichment in incompatible elements (Sr, K, Rb, Ba, Th), but almost similar abundance in compatible elements (P, Zr, Hf, Sm, Ti, Y, Yb) compared to Mid Oceanic Ridge Basalt (MORB).

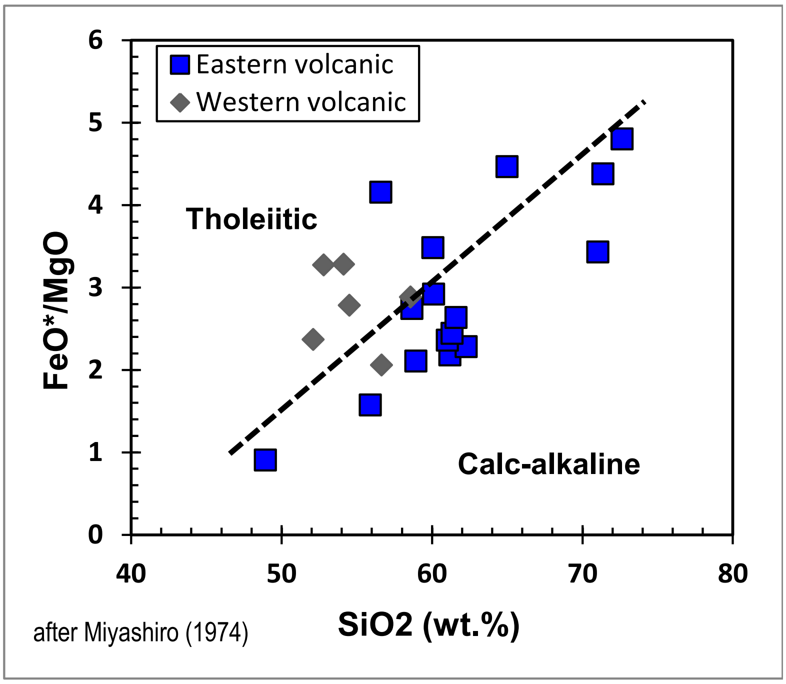

Figure 6. Plot of all volcanic in the diagram of SIO_2 versus FeO*/MgO showing classification of them into tholeiit and calc-alkaline affinity (after Miyashiro, 1974)

Table 2. Analytical Trace Elements results of volcanic from Central Sumatera (in ppm)

Sample	Sr	K	Rb	Ba	Th	Ta	Nb	Ce	P	Zr	Hf	Sm	Ti	Y	Yb
SL 22A	314	31619	99	677	10.7	0.7	11	69.3	1169	290	7.3	7	4389	46	5
SL 26	352	19403	80	365	7.7	0.3	4	43.8	887.8	144	4.2	5.4	4528	30	3.5
SL 28D	165	33494	134	454	6.4	0.4	3	26	397.5	112	3.4	3.1	1910	21	2.6
SL 38	318	17716	77	311	7.8	0.3	4	34.9	618.5	120	3.5	3.6	4282	18	2
SL 42	308	20587	110	407	12.7	0.5	5	53.8	707.4	169	4.9	4.5	3642	24	2.5
SL 43B	332	17060	79	359	8.6	0.5	6	51.7	840.2	170	4.9	5.6	4790	25	2.5
SL 03	68	35591	82	1033	10.8	0.4	6	53.1	221.4	133	3.9	3.7	984.6	24	2.7
SL 04	516	20495	63	450	3.1	0.2	3	36.9	1916	84	2.3	3.6	3811	15	1.7
SL 05	697	14860	51	350	3.2	0.2	3	25.4	1237	108	2.9	2.8	3081	14	1.8
SL 10	209	25091	84	617	8.9	0.7	8	55.5	675.9	211	6.1	5.7	2283	43	5.2
SL 14A	967	31671	115	1300	9.4	0.6	8	68.7	585.5	181	5.1	7.7	3296	45	4.7
SL 15	330	15782	53	415	6.2	0.3	4	41.2	726	112	2.8	5.8	3875	75	6.8
SL 18A	366	15734	62	380	6.4	0.4	4	46.8	809.9	142	3.9	6.4	3545	40	3.9
SL 32	366	17031	61	335	6.6	0.2	3	35.8	891.7	131	3.6	4	4456	21	2.4
SL 35	412	13417	43	376	6	0.3	4	45.7	1093	128	3.3	5.4	4558	34	3.1
SL 41	427	16006	61	414	7.2	0.6	7	44.7	891.2	127	3.3	3.7	4239	21	2.3
SL 47	330	3659	18	114	0.2	0.1	1	3.2	89.55	26	0.8	0.9	2410	7	0.7
SL 49B	104	49546	323	316	41.3	2	14	86.6	264.7	164	5.2	6.3	1066	37	4
PN 01A	418	10907	25	411	1.2	0.1	2	21.8	1121	81	2	3.3	5404	24	2.4
PN 5A	429	5888	21	218	2.3	0.2	4	28.5	1156	108	3	4.1	5725	28	3.3
PN 12A	578	4959	40	277	0.7	0.2	3	19.4	1035	74	1.9	3	5774	20	2.2
PN 08B	494	9521	23	323	3.3	0.2	4	47.5	1342	125	3.3	5.3	6331	26	2.7
ML 01	513	9521	28	237	3.3	0.3	4	34.7	1342	106	3	4.5	6331	22	2.3
ML 07A	475	9521	53	305	6.5	0.3	4	37.9	1342	110	3.1	4.2	6331	19	2

These patterns show strong similarity with the pattern of Island Arc Basalt (taken from Wilson, 1989) and directly confirm that the western volcanic of Central Sumatera is subduction related volcanic derived from island-arc tectonic setting. It means, the western part of the island is not continental component, but island-arc fragment.

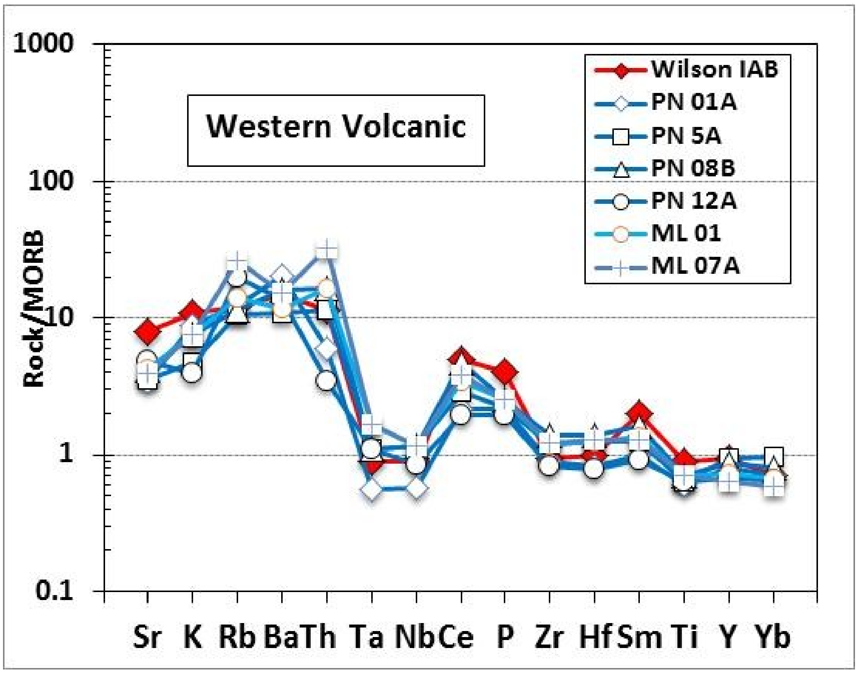

Figure 7. Plot of the western volcanic showing matched pattern with the rocks derived from island-arc setting, represented by Island Arc Basalt (Wilson, 1989)

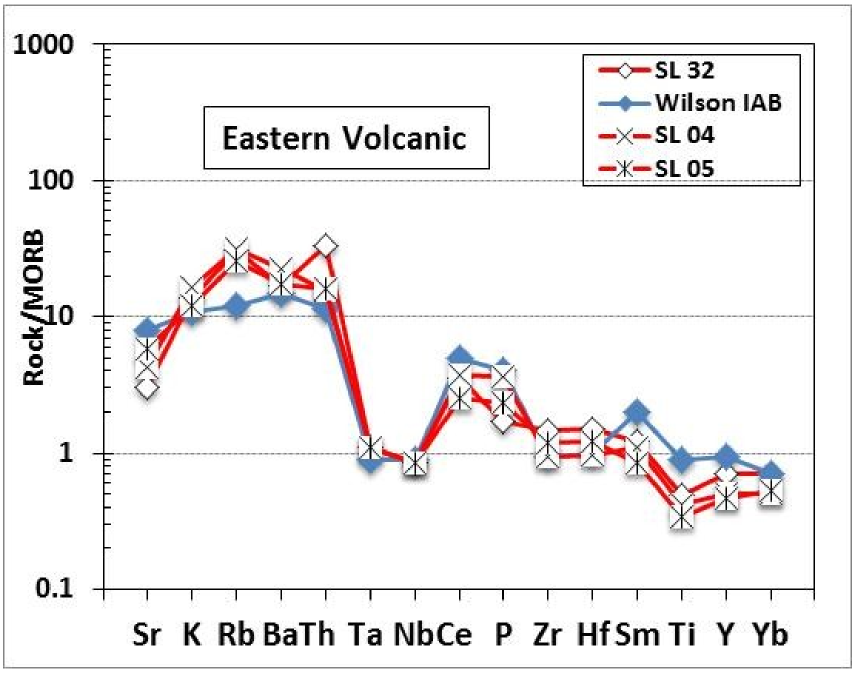

Figure 8. Plot of three samples of eastern volcanic showing strong similarity in pattern with the island-arc group.

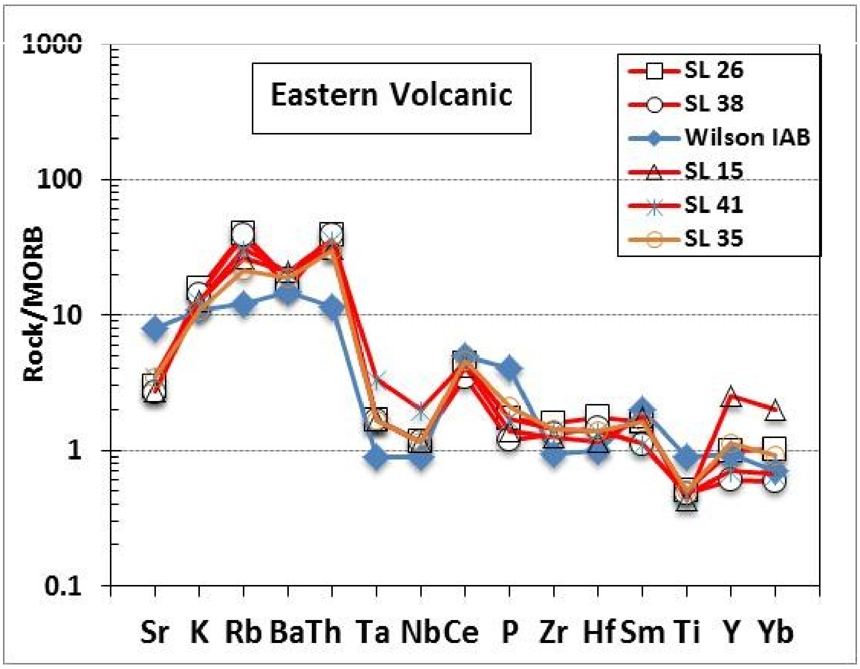

Figure 9. Plot of five samples of eastern volcanic showing strong similarity in pattern with the island-arc group.

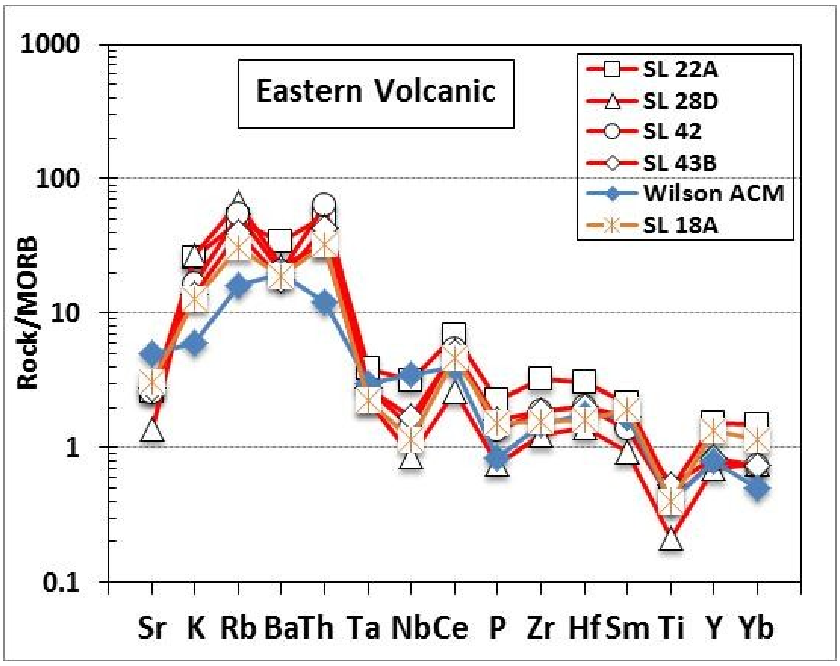

Figure 10. Plot of five samples of eastern volcanic showing continental character and matched with the pattern of Active Continental Margin, represented by ACM (taken from Wilson, 1989)

Samples from the eastern volcanic are also

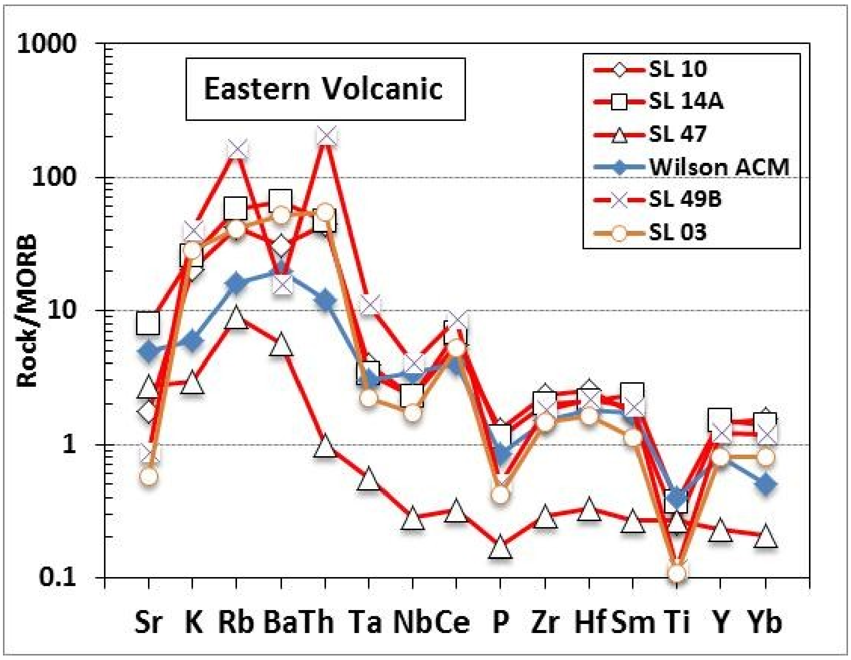

Figure 11. Plot of other five samples of eastern volcanic where one of them showing clear different pattern from the continental group.

plotted in spider diagrams and they show several different pattern. These various patterns indicate that the tectonic environment has been changed gradually eastwards, from island-arc character to continental character. Eight samples of eastern volcanic show very similar pattern with the island-arc group, although they also reflect part of the continental character such as lower Ti content compared to MORB (Figure 8 and 9). One of the samples indicates enrichment on Y and Yb (SL 15) and its causes are still not clear understood. Location of these eight samples can be classified as the eastern margin of the island-arc segment of the Central Sumatera.

Plot of other 10 samples from eastern volcanic group in spider diagram give a good confirmation about the continental character of the region, although they show various enrichment in incompatible elements and depletion in compatible elements (figure 10 and 11). However, the unusual sample (SL 47) shows different pattern than the continental group (Figure 11). The rock is slightly enriched on incompatible elements but very depleted on compatible elements and it confirms strongly that this rock is not derived from magma in the continental tectonic setting.

Rare Earth Elements (REE)

The continuation of island-arc origin of the western part of Sumatera is confirmed based on the major and trace elements in the volcanic of Central Sumatera. The evidences found through the geochemical signatures of volcanic in Lampung and Bengkulu regions (Zulkarnain, 2011, 2012) are strongly confirmed by the geochemical patterns of major and trace elements of the volcanic in Central Sumatera. However, to get more supporting data and reasons for that, it is still necessary to find out more evidences from their REE. All 18 samples of the eastern volcanic were analyzed chemically for REE and the results are given in the Table 3.

Table 3. Analytical results of Rare Earth Elements of western and eastern volcanic in Central Sumatera (in ppm)

Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
SL 22A	33.1	69.3	8.3	31.2	7	1.62	7.1	1.2	7.5	1.6	4.9	0.77	5	0.74
SL 26	21.1	43.8	6.11	22.9	5.4	1.34	5.2	0.9	5.3	1.1	3.6	0.54	3.5	0.51
SL 28D	11.9	26	3.13	12.7	3.1	0.69	3.2	0.6	3.6	0.8	2.5	0.39	2.6	0.39
SL 38	15.9	34.9	4.36	15.8	3.6	1	3.5	0.6	3.4	0.7	2.2	0.32	2	0.31
SL 42	24.9	53.8	5.9	20.8	4.5	1.05	4.3	0.7	4.3	0.9	2.7	0.4	2.5	0.37
SL 43B	23.3	51.7	6.55	24.3	5.6	1.37	5	0.8	4.7	0.9	2.8	0.41	2.5	0.35
SL 03	27.3	53.1	5.53	18.4	3.7	0.62	3.4	0.6	3.9	0.9	2.7	0.41	2.7	0.42
SL 04	17.7	36.9	4.34	16.2	3.6	0.99	3.3	0.5	2.9	0.6	1.8	0.27	1.7	0.25
SL 05	12.1	25.4	3.12	11.9	2.8	0.8	2.6	0.4	2.7	0.6	1.8	0.27	1.8	0.26
SL 10	25.9	55.5	6.47	25.3	5.7	1.18	6.1	1.2	7.4	1.6	5	0.8	5.2	0.78
SL 14A	31.9	68.7	8.71	33.6	7.7	2.14	7.6	1.3	7.6	1.6	4.9	0.75	4.7	0.69
SL 15	27.6	41.2	6.21	24.5	5.8	2.04	8.5	1.4	8.7	2	6.5	1.06	6.8	0.99
SL 18A	27.4	46.8	7.4	27.9	6.4	1.86	6.6	1.1	6.6	1.3	4.1	0.61	3.9	0.58
SL 32	15.8	35.8	4.43	16.9	4	0.98	3.9	0.6	3.8	0.8	2.4	0.37	2.4	0.34
SL 35	25.4	45.7	6.49	24.1	5.4	1.56	5.4	0.8	4.9	1.1	3.3	0.5	3.1	0.47
SL 41	24.2	44.7	4.92	17.2	3.7	1.11	3.6	0.6	3.7	0.8	2.3	0.36	2.3	0.34
SL 47	1.2	3.2	0.49	2.5	0.9	0.37	1.2	0.2	1.4	0.3	0.9	0.12	0.7	0.11
SL 49B	43.2	86.6	8.99	30.5	6.3	0.76	5.7	1	6.2	1.3	4	0.61	4	0.59
PN 01A	9.2	21.8	2.86	12.2	3.3	1.06	3.7	0.6	4.1	0.8	2.6	0.38	2.4	0.35
PN 5A	12.2	28.5	4.03	16.4	4.1	1.33	4.4	0.7	4.7	1	3.2	0.5	3.3	0.47
PN 12A	8.2	19.4	2.56	11.1	3	1.11	3.3	0.6	3.7	0.8	2.3	0.35	2.2	0.33
PN 08B	21.8	47.5	5.83	22.7	5.3	1.54	5.1	0.8	4.7	1	2.9	0.43	2.7	0.4
ML 01	15.3	34.7	4.73	18.4	4.5	1.35	4.1	0.7	3.9	0.8	2.5	0.37	2.3	0.33
ML 07A	18.5	37.9	5.01	18.9	4.2	1.16	3.9	0.6	3.5	0.7	2.2	0.31	2	0.31

Table 3 shows various content of the REE among the western and eastern volcanic groups itself and between the two groups. No significant different content can be recognized based only on their elements content, except one sample, the unusual sample (SL 47). The last sample contains very low abundance on all rare earth elements compared to other samples.

To get more clear comparison of the REE abundance among all samples, the analytical results are normalized to chondrite and then plotted in spider diagrams. Plot of the western volcanic in the REE spider diagram shows that all the rocks have similar pattern with various enrichment on Light REE or LREE (La, Ce, Pr, Nd and Sm), ranging from 30 to less than 100 times of chondrite and slightly enrichment on Heavy REE or HREE (Figure 12) compared to chondrite. This pattern is typically for the island-arc environment.

phenomenon reflects influence trace of continental character in the island-arc environment, so that the region should be a transition zone from island-arc to continental settings.

The other five samples having also island-arc character in trace elements spider diagram (Figure 9) are also plotted in the REE spider diagram. Their patterns in the spider diagrams seem to be similar with the western volcanic, but they are more enriched on the HREE (Figure 14). The rocks are slightly high on LREE compared to the western volcanic and small kick point at Eu element still can be recognized in some of them. These patterns reflect also influence trace of continental character in island-arc environments.

Meanwhile, ten other samples of eastern volcanic are also plotted in the REE spider diagrams and the results are shown in Figure 15 and 16. Five of the ten samples are significantly enriched on

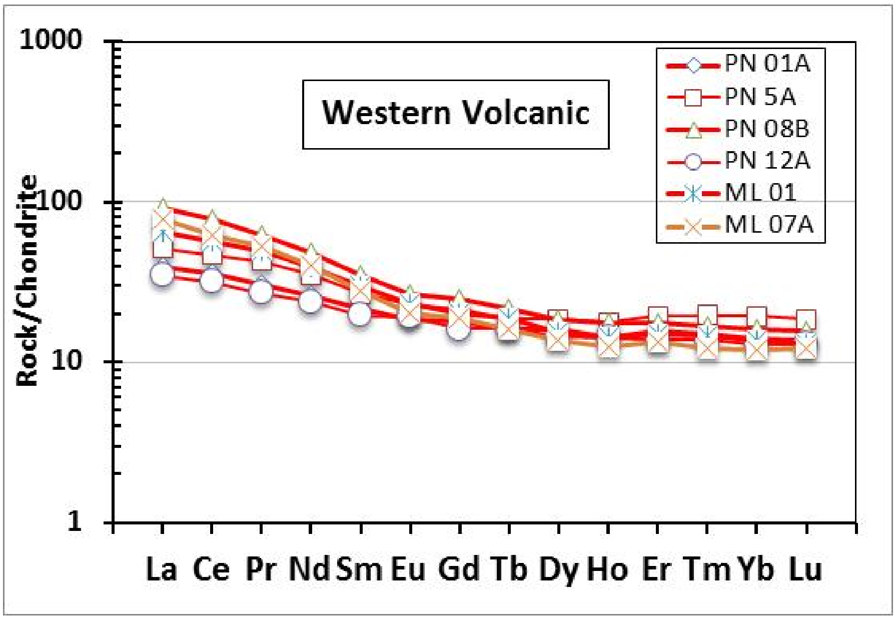

Figure 12. Plot of samples of western volcanic in the REE spider diagram showing specific pattern for island-arc tectonic setting

The eight rock samples of eastern volcanic showing island-arc pattern in the trace elements spider diagrams are also plotted in REE spider diagrams. The patterns of three samples of them are very similar with the patterns of western volcanic, although they have a small kick point at Eu element, probably resulted by effect of crystallization of plagioclase (Figure 13). This

LREE (up to more than 100 times of chondrite), except sample SL 28D and they are also slightly enriched on HREE (Figure 15). However, they show similar patterns among them with clear kick points on Eu element and it is a very common mark on rocks derived from magma in continental environments.

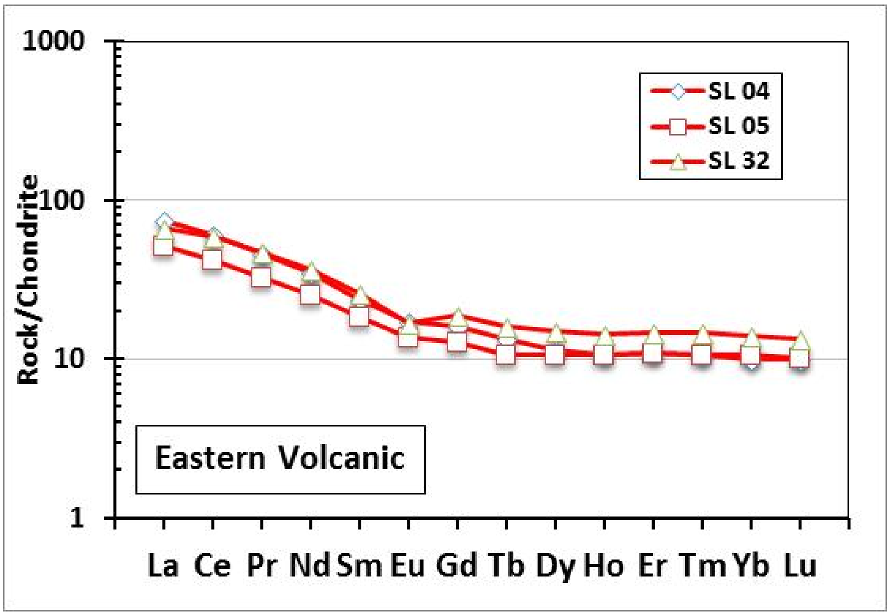

Figure 13. Plot of three samples of eastern volcanic showing pattern of island-arc environment, but with small kick point on Eu reflecting continental influences.

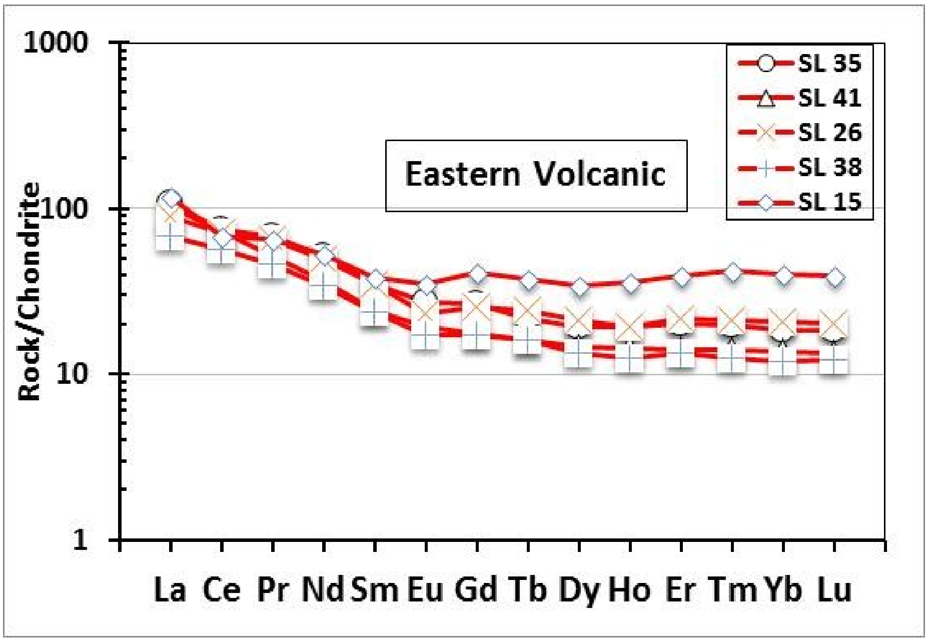

Figure 14. Plot of the five samples of eastern volcanic showing island-arc pattern but with various enrichment on Heavy REE and small kick points on Eu element.

Four of the other five samples show similar pattern with the previous mentioned five samples, where they are significantly enriched on LREE, showing clear kick points at Eu element and slightly enriched on HREE (Figure 16). They are completely reflecting the common signatures for rocks derived from magma in the continental environment.

In the above spider diagram, it can be recognized

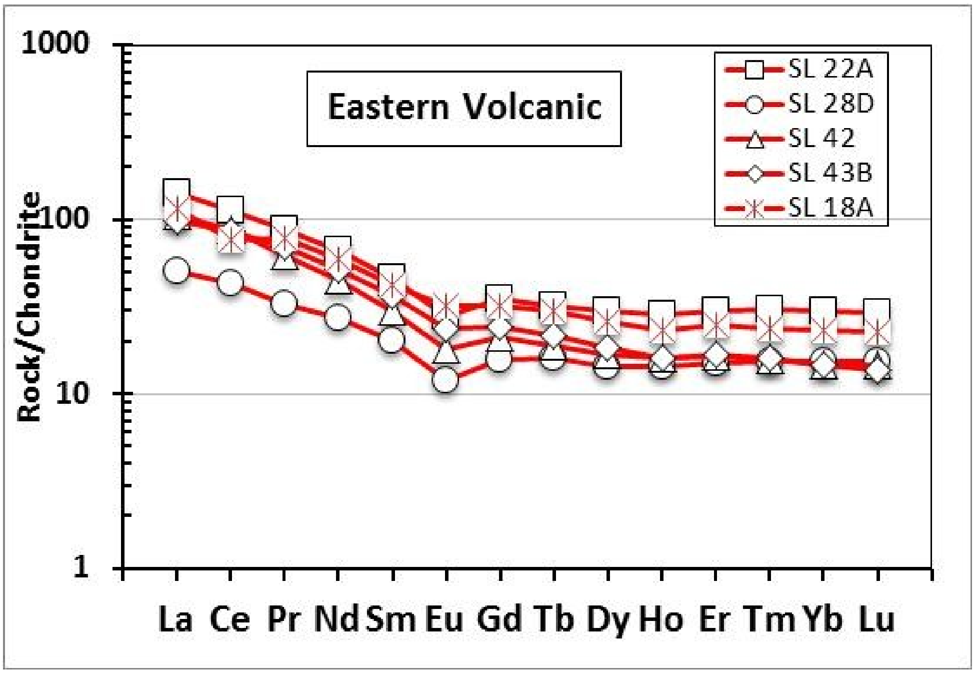

Figure 15. Plot of five samples of eastern volcanic showing continental character.

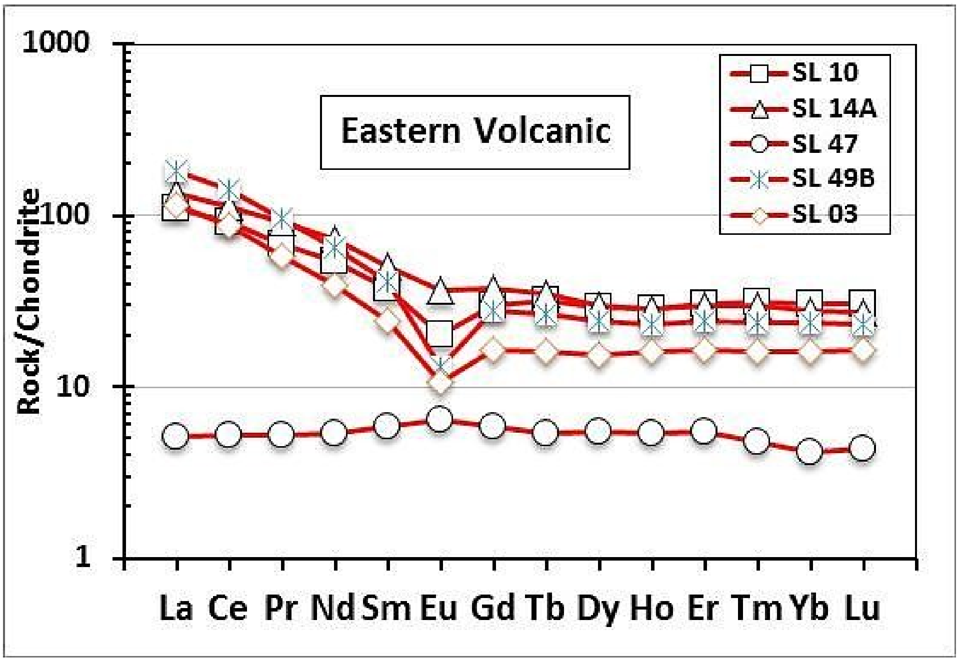

Figure 16. Plot of other five samples of eastern volcanic showing continental character where one of them reflecting back-arc basin environment.

clearly that one of the samples show very different pattern compared to other samples from eastern volcanic, namely the unusual sample. The rock shows a flat trend from LREE to HREE and showing ratio rock/chondrite less than 7 times chondrite. This pattern is very similar with rocks pattern derived from magma in the back-arc basin environment (Wilson, 1986).

DISCUSSION

It is already mentioned previously that the aim of this paper is to discuss the geochemical signatures of the volcanic in Central Sumatera in order to confirm whether the island-arc character of the western part of Sumatera continues from Lampung and Bengkulu to the north or it is only pseudo evidences that rise locally. Based on the trace and rare earth elements signatures found out in the volcanic in Lampung and Bengkulu regions, a preposition for the tectonic environment of the western part of Sumatera was proposed. It is believed that the western part of Sumatera is a strange fragment having long and complicated geological history before it came and collided to the eastern part of Sumatera that belongs to continental margin of Eurasia. Although the fragment nowadays has been identified consisting of several micro continents or continental fragments and covered also by Woyla Terrains, but the bedrock or the main component of the western part of Sumatera shows island-arc character. These evidences lead to understanding that Sumatera is not a homogeneous island that belongs to active continental margin of Eurasia, but it consists of two different parts where the western part is island-arc fragment and the eastern part belong to Eurasia continental margin. The evidences for island-arc character of the western part of Sumatera have been revealed through geochemical signatures of volcanic in Lampung and Bengkulu regions (Zulkarnain, 2011, 2012). Therefore, it is needed to trace and to find out such evidences in all volcanic that cropped out in the western coast of the island in order to proof the preposition.

Major elements signatures of the samples reflect the occurrences of two different tectonic environments where the rocks have been formed. The western volcanic is typically subduction related products with island-arc character having intermediate composition in narrow range, while the eastern volcanic shows wide range composition dominated by more acidic rocks indicating subduction related volcanic with continental character (Figure 5). The clues are confirmed when the rocks plotted in the affinity diagram, where all rocks of western volcanic belong to tholeiitic type and most of the eastern volcanic classify as calc-alkaline type (Figure 6). Some of the rocks of eastern volcanic are also distributed in the tholeiitic zone and it indicates that the changing of the tectonic environment in the regions occurred gradually to the east.

The existing of two different tectonic environments in Central Sumatera is strongly supported by the geochemical signatures of trace elements. Patterns of the samples in the spider diagrams show clearly that there are two different tectonic setting where the rocks have been generated from magmas. All samples of western volcanic represent strong similar pattern with Island Arc Basalt, as well as some samples of the eastern volcanic (Figure 7, 8 and 9). It has proofed that the rocks should be derived from magmas in island-arc tectonic setting. The patterns of other samples from the eastern volcanic show similarity with those of the rock generated in the continental setting (Figure 10 and 11). Some of them have variation in their pattern compared to the rocks generated in the tectonic setting, indicating influence traces of the island-arc character. Besides that, the trace elements signatures reveal also the third tectonic environment, namely back-arc basin tectonic setting to where one of the eastern volcanic samples belongs (Figure 11). These data indicate that the tectonic history of the Sumatera is not as simple as thought before. The western part of Sumatera is classified as fragment with island-arc character and it is confirmed from Lampung to Bengkulu region. However, in Central Sumatera, the fragment does not show only the island-arc character but there is evidence indicating their development into back-arc basin.

To get more clear discrimination among the three tectonic environments, all samples are plotted in the diagram of (Ta/Nb)N versus (Ti/Ce)N. Three different tectonic environments can be distinguished very clearly in the diagram consisting of Active Continental Margin (ACM), Island-arc and Back-arc basin tectonic settings. The ACM setting are characterized by wide range of (Ta/Nb)N ranging from 1.2 to 2.8 but with ratio of (Ti/Ce)N less than 0.1, while the island-arc setting are marked by higher ratio of (Ti/Ce)N, varying from 0.15 to 0.3, but in narrow ratio of (Ta/Nb)N, between 1.0 to 1.5 (Figure 17). The back-arc basin setting is separated far away from the others and marked by high ratio of (Ti/Ce)N, up to more than 0.8.

patterns of eastern volcanic in spider diagrams figure three different patterns reflecting three different tectonic environments. The first pattern is quite similar with the western volcanic, representing the island-arc tectonic environment (Figure 13 and 14). The second one is characterized by higher enrichment on LREE and HREE than the island-arc ones and marked by clear kick points at Eu element (Figure 15 and 16). These kick points are interpreted as effect of plagioclase crystallization during magma

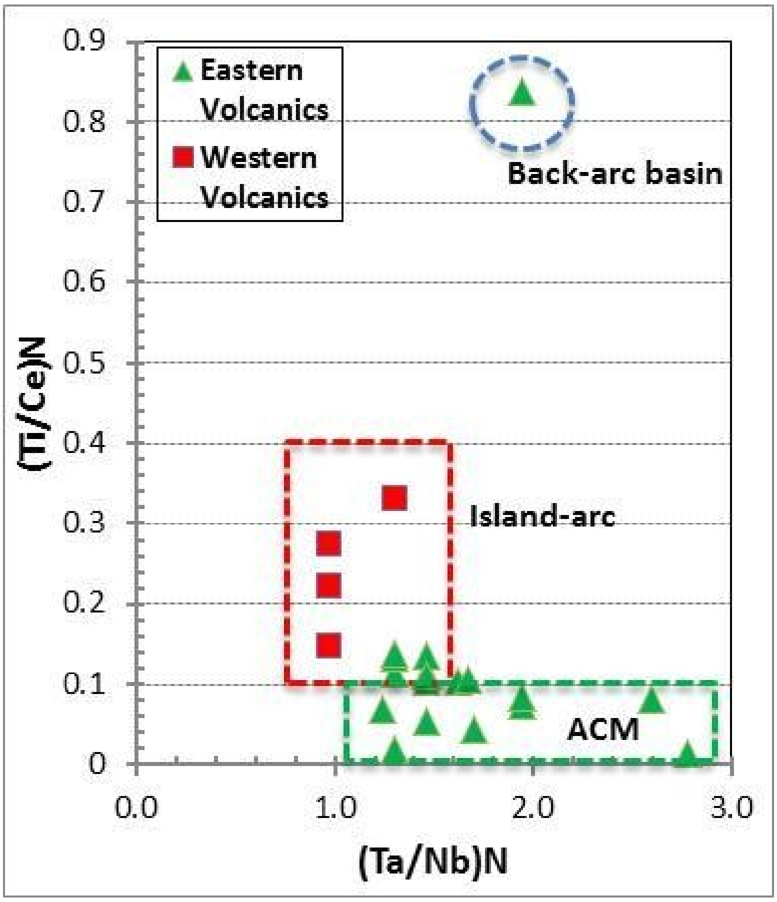

Figure 17. Plot of samples from western and eastern volcanic in Central Sumatera showing three different tectonic environments.

The three identified tectonic environments are also confirmed by the geochemical signatures of rare earth elements. The patterns of REE in spider diagram for western volcanic show various enrichment in LREE but less than 100 times of chondrite and slightly enrichment on HREE, less than 30 times of chondrite (Figure 12). These patterns are matched with the rocks pattern generated in island-arc tectonic setting. The fractionation and it is a common feature in the continental tectonic setting. The third pattern is shown only by one sample (previously mentioned as unusual sample) where the rocks are depleted in all rare earth elements and showing almost flat pattern (Figure 16). This pattern is similar with rocks pattern derived from magmas in the back-arc basin environment.

To get clearer figure of the three tectonic environments based on the REE, all samples are plotted in the diagram of (La/Lu)N versus (Sm/Eu)N as shown in Figure 18. The island-arc tectonic setting is characterized by relatively wide range of ratio (La/Lu)N ranging from 2.6 to 8, but they have ratio of (Sm/Eu)N less than 1.4. In the other hand, the ACM tectonic setting is represented by higher ratio of (Sm/Eu)N that is more than 1.5 and having similar ratio of (Sm/Eu)N with the island-arc ones. Meanwhile, the back-arc basin tectonic setting is marked by low ratio of (La/Lu)N, less than 1.9.

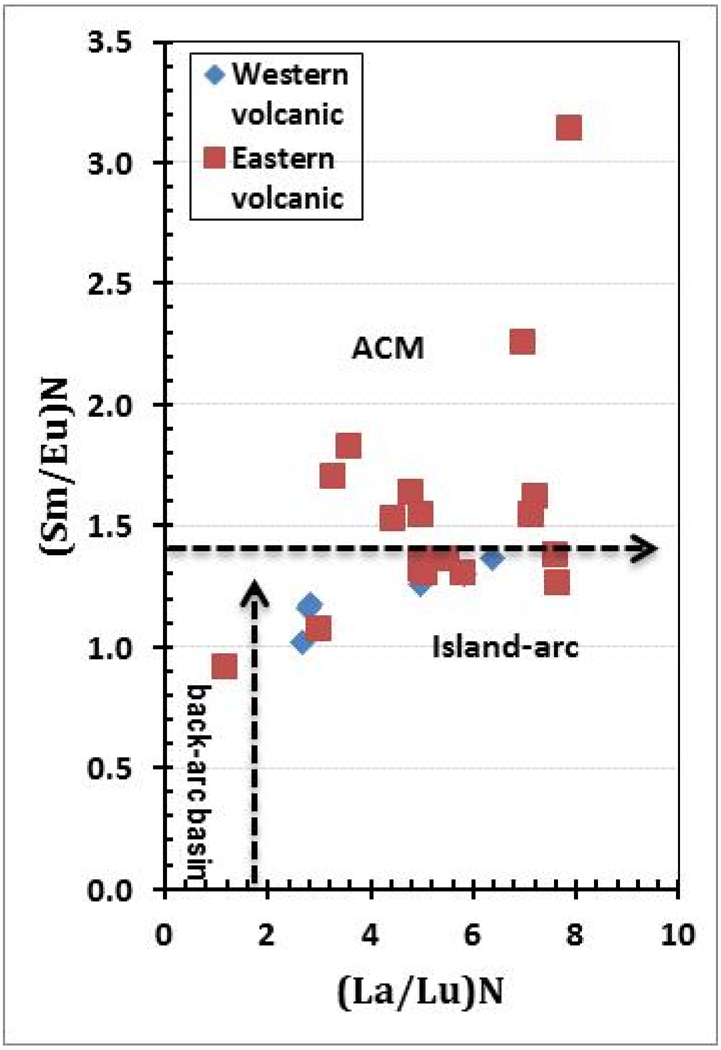

Figure 18. Plot of the samples from western and eastern volcanic in Central Sumatera showing three different tectonic environment.

CONCLUSION

Based on the above discussion, it can be conclude that the geochemical signatures of western and eastern volcanic in Central Sumatera have confirmed that the island-arc character of the western part of Sumatera can be traced clearly from Lampung through Bengkulu to Central Sumatera. In other words, it can be concluded that the preposition assuming the western part of Sumatera is island-arc fragment and not part of Eurasia continental margin is still confirmed up to Central Sumatera. In Central Sumatera, the western fragment of the island does not give evidences only for island-arc character, but also include indications for developing back-arc basin in the region in the past. These data have given signals that the tectonic history of Sumatera looks like to be more complicated and could be different from one segment to another segment along the western coast of the island.

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