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RISET
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SUMATRA IS NOT A HOMOGENEOUS SEGMENT OF GONDWANA DERIVED CONTINENTAL BLOCKS: A NEW SIGHT BASED ON GEOCHEMICAL SIGNATURES OF PASAMAN VOLCANIC IN WEST SUMATRA

Sumatera Sebagai Sebuah Segmen Blok Benua Tidak Homogen Berasal dari Gondwana: Sebuah Pandangan Baru Berdasarkan Ciri Geokimia Batuan Volkanik Daerah Pasaman, Sumatera Barat

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ABSTRACT Many authors have written and drawn that Sumatra is a homogeneous continental segment because it was constructed by continental blocks derived from Gondwana in different time and periods since initiation of Sundaland in the Triassic. There is an idea to suggest that Sumatra is fully recognized as a continental margin of Sundaland, while another idea draws that Sumatra consists of Sibumasu, West Sumatra Block and continental crust accreted onto Sundaland. However, both ideas have shown that Sumatra is composed of continental blocks. Geochemical signatures of Pasaman volcanic, collected from West Sumatra, using Ta/Yb versus Th/Yb discriminant diagram indicate that the rocks are derived from two different tectonic settings, not only from active continental margin (ACM) but also from oceanic arc tectonic environments. The discrimination becomes more clear and explicit in Yb (ppm) versus Th/Ta diagram where the ACM-derived rocks have Th/Ta ratio between 6-20 while the arc-derived samples show the ratio greater than 20. Identification of the tectonic setting origin of the volcanic can also be done using spider diagrams of selected trace elements, but it is not possible based on spider diagrams of REE. The geochemical signatures of Pasaman volcanic give evidence that Sumatra actually is not a homogenous segment of Gondwana-derived continental blocks, but consists of two different segments including ACM and arc tectonic settings. These evidences strengthen previous studies results in Lampung, Bengkulu and Central Sumatra.

Keywords: Sumatra, Pasaman, non-homogeneous segment, tectonic setting, continental, arc, trace elements, discriminant diagram.

ABSTRAK *Banyak penulis yang telah menulis dan menggambarkan bahwa Sumatera adalah sebuah segmen benua yang homogen, karena ia disusun oleh sejumlah blok bersifat benua yang berasal dari Gondwana dalam waktu dan periode yang berbeda-beda sejak pembentukan Sundaland pada Zaman Trias. Terdapat pemikiran yang menganggap bahwa Sumatera sepenuhnya dikenali sebagai tepian benua dari Sundaland, sementara itu pendapat lain menggambarkan bahwa Sumatera terdiri dari Sibumasu, Blok Sumatera Barat dan kerak benua yang didorong naik ke atas Sundaland. Namun demikian, kedua pendapat tersebut menunjukkan bahwa Sumatera dibentuk oleh blok-blok benua. Ciri geokimia batuan volkanik daerah Pasaman, yang dikumpulkan dari Sumatera Barat, dengan*

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menggunakan diagram pembeda Ta/Yb terhadap Th/Yb menunjukkan, bahwa batuan-batuan tersebut berasal dari dua lingkungan tektonik yang berbeda, tidak hanya dari tepian benua aktif (ACM), tetapi juga dari lingkungan tektonik busur lautan. Pembedaan itu menjadi lebih jelas dan eksplisit di dalam diagram Yb (ppm) terhadap Th/Ta, dimana batuan-batuan yang berasal dari ACM memiliki rasio Th/Ta antara 6 dan 20, sementara itu conto batuan yang berasal dari lingkungan busur menunjukkan rasio yang lebih besar dari 20. Identifikasi lingkungan tektonik asal dari batuan volkanik dapat juga dilakukan dengan menggunakan diagram laba-laba dari unsur-unsur jejak terpilih, akan tetapi tidak mungkin dilakukan berdasarkan diagram laba-laba dari unsur REE. Ciri geokimia batuan volkanik daerah Pasaman tersebut memberikan bukti-bukti bahwa Sumatera sesungguhnya bukanlah sebuah segmen homogen yang berasal dari blok-blok benua Gondwana, akan tetapi terdiri dari dua segmen berbeda yang mencakup lingkungan ACM dan busur. Bukti-bukti ini memperkuat hasil penelitian sebelumnya di Lampung, Bengkulu dan SumateraTengah.

Kata kunci: *Sumatera, Pasaman, segmen tak homogen, lingkungan tektonik, bersifat benua, busur, unsur-unsur jejak, diagram pembeda.*

INTRODUCTION

Sumatra is one of the five biggest islands in Indonesia (Sumatra, Java, Kalimantan, Sulawesi and Papua), located in the most western area of Indonesian Archipelago. The length of the island is about 1650 km, and its width varies from less than 100 km in the north to around 350 km in the south.

Tectonically, Sumatra as well as most parts of Indonesia region, belongs to Sundaland block. The Sundaland was initiated once Sibumasu and Indo China-East Malaya continental blocks were collided in the Triassic forming the Sundaland Core (Hall, 2009). The core covers most of the Sumatra, including all of the eastern part of the island and more than half of the western. Through later collisions of continental blocks during Early and Late Cretaceous and Early Miocene, the Sundaland was extended, including all Sumatra, Java, Bali, Lombok, Sumbawa, Kalimantan, and Sulawesi (Figure 1).

Specifically, Sumatra is formed by two continental blocks and continental crust accreted to Sundaland (Metcalfe, 2006; 2011). The two continental blocks were derived from Gondwana Land, namely Sibumasu block in the eastern part of the island with the age of Early Permian, and

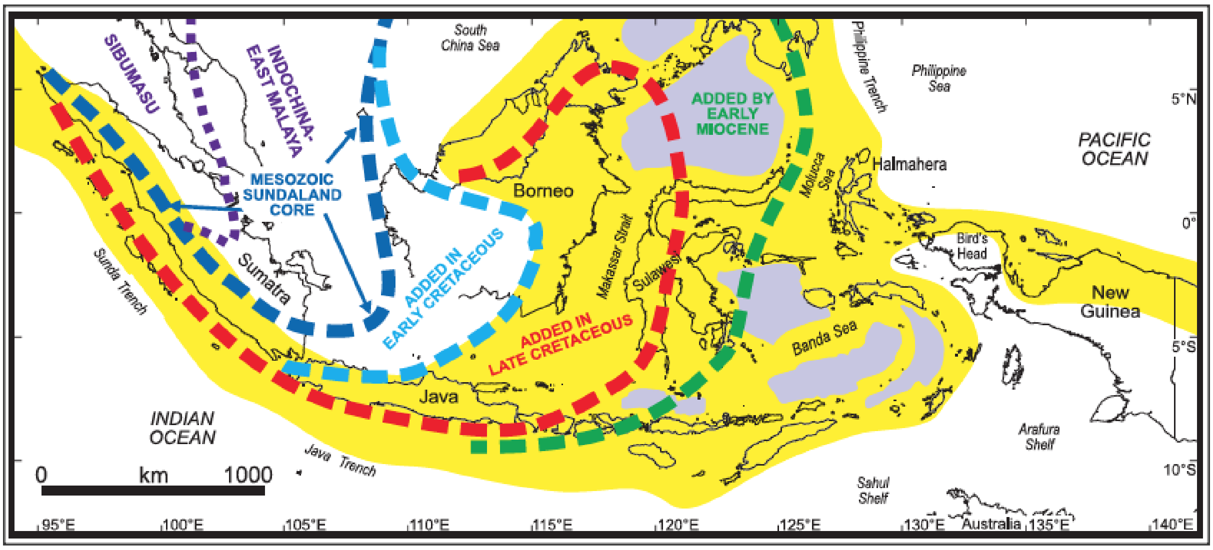

Figure 1. The evolution of Sundaland initiated by collision of Sibumasu and Indo China-East Malaya continental block in the Triassic and extended through collision of continental blocks during Early Cretaceous to Miocene (Hall, 2009).

West Sumatra block that is Devonian in age (Figure 2). Both blocks are situated from Sumatra Fault Zone (SFZ) to the east while the continental crust is distributed from the SFZ to the west till to the subduction zone during the Cretaceous to Cenozoic (Metcalfe 2011).

Geologically, Sumatra is composed of various rocks, including sediments, volcanic, intrusive- and metamorphic rocks with age ranging from Palaeozoic to Quaternary/Recent (Crow and Barber, 2005). The volcanic is the youngest rock on the island, ranging from Eocene to Holocene.

Along the western side of the island, the Woyla Group (Lower Cretaceous-Upper Jurassic) crops out in a certain spotted area such as in Aceh, near Natal, Silungkang and Kerinci. Most of the Woyla outcrops are in contact with the Kluet-Kuantan Formations (Lower Permian-Lower Carboniferous) or with Palepat, Silungkang, and Mengkarang Formations (Lower Permian), where all the Formations belong to continental West Sumatra Block (Crow and Barber, 2005). The Woyla Group is an intra-oceanic arc that collided with the Sumatra margin at 90 Ma and caused termination of subduction beneath Sundaland (Hall *et al*., 2009). Between 90 – 45 Ma, the Sundaland was surrounded by inactive margins and no subduction beneath Sumatra and Java during this period due to the position of Australia that remained close to Antarctica. At 45 Ma, Australia began to move north and since that time, subduction zones in Indonesian region has been active until the recent time.

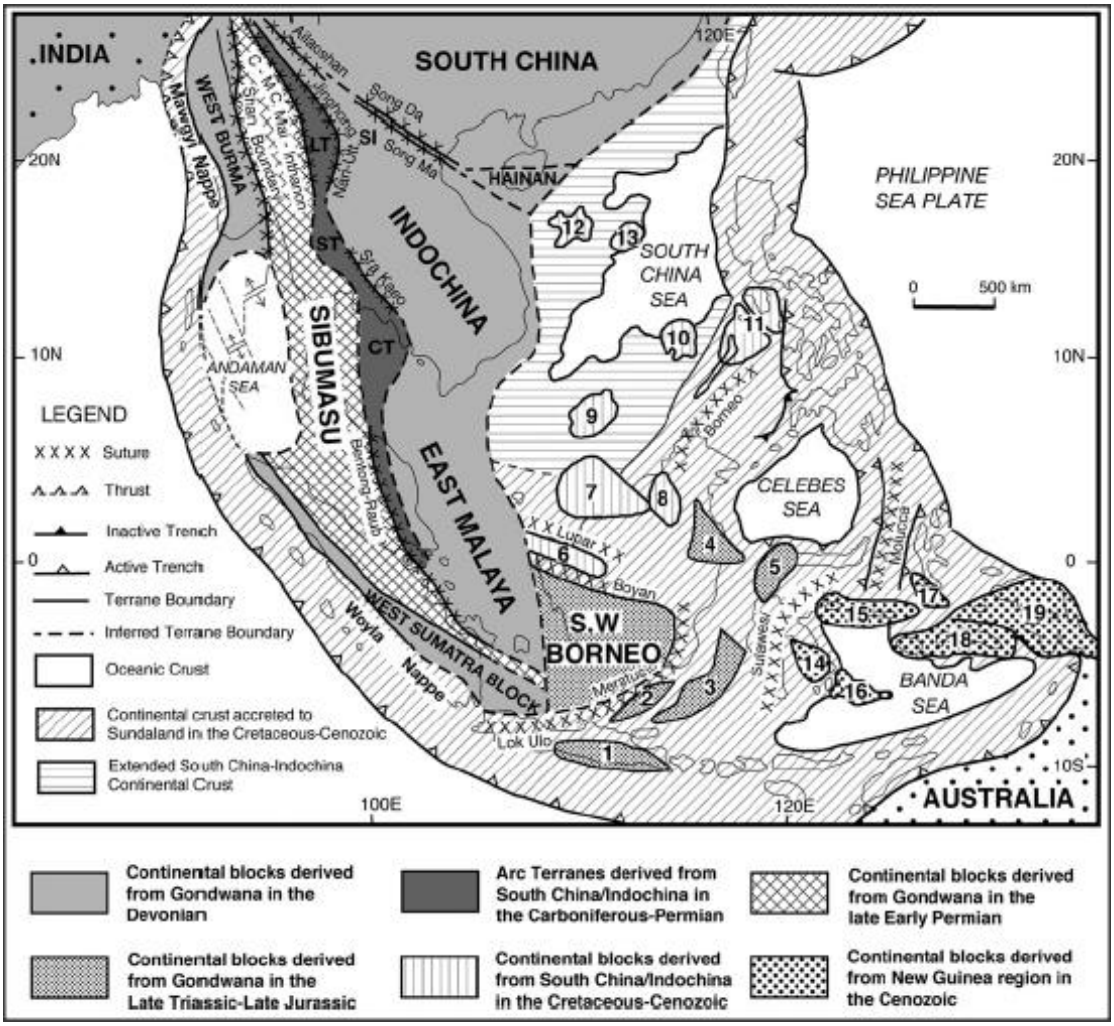

Figure 2. Tectonic map of Sundaland showing that Sumatra is formed by three continental blocks consisting of Sibumasu, West Sumatra Block and Continental crust accreted to Sundaland in the Cretaceous-Cenozoic (Metcalfe, 2011).

Although there are outcrops of the Woyla Group on the western side of Sumatra that interpreted as an intra-oceanic arc which has collided with the Sumatra margin during Cretaceous to Upper Jurassic, many authors have considered and drawn that Sumatra is still a homogeneous continental block derived from Gondwana in a different time. Probably, they consider that the Woyla Group are only in nappe form. Meanwhile, geochemical signatures of Tertiary volcanic from Lampung, Bengkulu and Central Sumatra (around Solok area) reported that Sumatra is composed of two different tectonic characters, namely island-arc in the west and continental in the east side (Zulkarnain, 2011; 2012; 2014). The aim of this paper is to reveal that Sumatra is not a homogeneous segment of continental crust through delivering evidence based on rock geochemical signatures from Pasaman area, West Sumatra.

GEOLOGICAL SETTING

Pasaman is located in West Sumatra Province, between Lubuk Sikaping and Kota Nopan, where the Pasaman Regency is situated from Sumatra Fault Zone to the west (Figure 3).

The Pasaman area is dominated by Tertiary undifferentiated volcanic, accompanied by Pre-Tertiary rocks including Late Cretaceous Kanaikan granites and Kuantan Formation and also member of Woyla Group consisting of mélanges, peridotite/serpentinite, limestone and Sikubu Formation. The area is cut by the NW-SE Pasaman Fault that meets with the Kanaikan Fault Zone (KFZ) in the south. In the north, Pasaman is bordered by Muarasoma area that dominated by Muarasoma Formation together with Belok Gadang- and Sikubu Formations, which belong to the Woyla Group. It is also covered by a smaller amount of Tertiary Langsat volcanic.

Detailed geology of Pasaman is mapped and published by Rock *et al.* (1983) in Geological Map of the Lubuk Sikaping sheet. Variation of rocks in the Pasaman area is quite high where almost all kind of rocks can be found in the area, and their age ranges from Paleozoic to Recent. The oldest rock in the Pasaman area is Kuantan Formation that formed by low-grade metamorphic rocks consisting of slate, quartzite and arenite meta-quartz wacke that is Permo-Carbon to Permo-Trias in age. Other Pre-Tertiary rocks in the area are Ultramafic Pasaman Group including harzburgite, serpentinite, dunite and pyroxenite (Jura-Cretaceous), Undifferentiated Mesozoic Layer comprised of meta-volcanic, hornfels, slate, and minor limestone (Paleozoic-Cretaceous) and

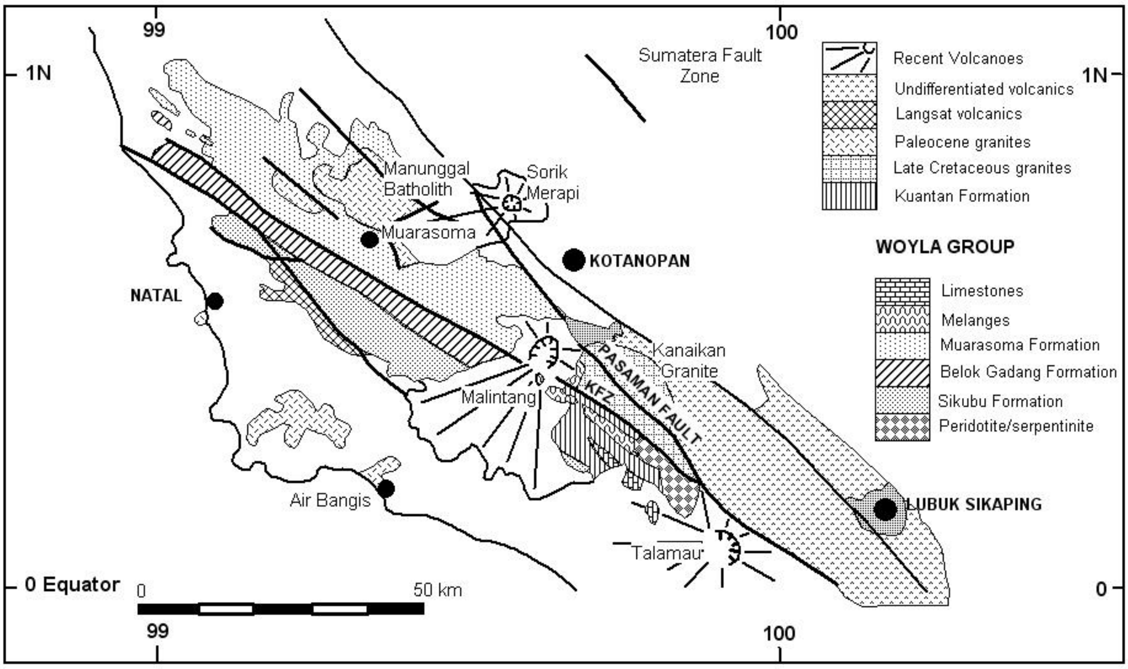

Figure 3. Simplified geological map of Pasaman and Muarasoma areas (Zulkarnain, 2005).

Silungkang Formation dominated by limestone and meta-limestone. Tertiary rocks cover most of the area, particularly rocks so called Undifferentiated, namely volcanic without traces of eruption center (Miocene), and Talamau volcanic (Pleistocene-Holocene). The volcanic used and discussed in this paper were collected from the Tertiary Undifferentiated rocks.

SAMPLE COLLECTION AND PREPARATION

There are more than 35 outcrops that were observed during fieldwork, but samples are not collected from each location due to the fresh condition of the rocks. Only fresh rocks were sampled. The area was accessed through two ways, namely from Lubuk Sikaping (the Pasaman Regency) to Panti and turn to the west to Cubadak, Simpang Tonang and Simpang Dingin. The second way is from Simpang Empat (the West Pasaman Regency) to the north via Pinagar, Talu to Simpang Tonang and Simpang Dingin.

Around 20 samples of Tertiary Undifferentiated rocks were collected from the northern and southern part of the area, and there are two samples were taken at the foot of the Talamau Volcano in the south representing Pleistocene-Holocene volcanic (Figure 4).

In the north, the samples were collected along the Sinabuan River and near the Simpang Dingin village. While in the south, the samples were taken at the river in Pinagar village, near Petok (on the road side from Panti to Lubuk Sikaping), and in the foot hill, north side of Bonjol, where local people run artisanal mining.

For rock chemical analysis, selected samples were prepared into powder form in suitable grain size and then the samples were sent to Activation Laboratories in Ontario, Canada for major, selected trace and rare earth elements analysis under 4LITHO analysis code.

GEOCHEMICAL SIGNATURES

The basic reason why geochemical signatures are used in this paper as evidence to identify the tectonic origin of the Pasaman area is that the pattern of selected trace elements in volcanic rocks is unique and different from one tectonic environment to others. Many previous workers have been successfully used discriminant diagrams in the past to identify the tectonic

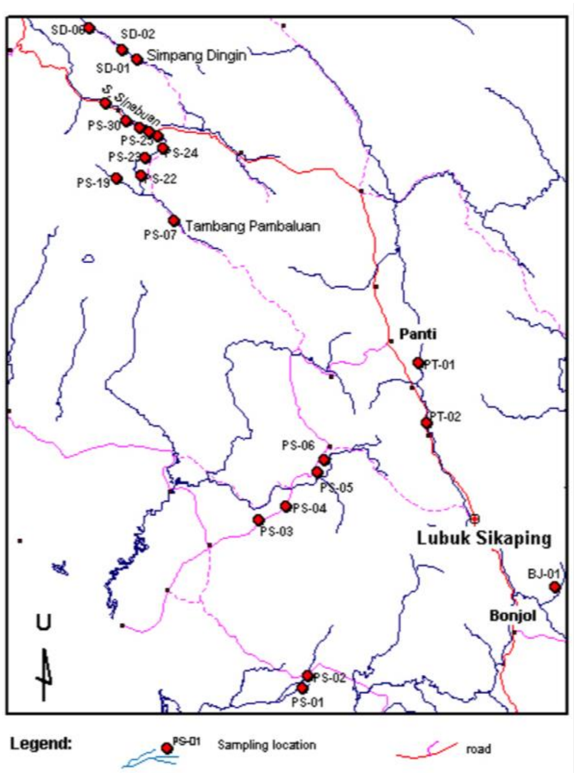

Figure 4. Sampling location of the Pasaman volcanic (Zulkarnain, 2005).

environments of ancient and modern mafic igneous rocks (Pearce, 1982; 1983; 1996; Pearce & Peate, 1995; Winchester & Floyd, 1977; Winchester *et al.*, 1992; Wood, 1980). These diagrams are based on the empirical observations that show systematic chemical differences in source characteristics of basic magmas erupted in different tectonic settings.

Some of the trace elements such as Th, U, Ce, Zr, Hf, Ti, Ta, and Nb are classified as High Field Strength Elements (HFSE). Some others with large ion size such as Rb, Ba, Cs, K, Sr, Pb, and Eu are grouped as Large Ion Lithophile Elements (LILE). Among the HFSE members, Th is the least immobile element because its z/r ratio is the lowest one. Therefore, sometimes this element shows characters similar to incompatible elements. Both groups are very common to use in the form of geochemical signatures pattern of volcanic to identify the tectonic setting from where the volcanic derived. Ta and Th are already proven to be effective in identifying tectonic environments of basaltic rocks because basalts derived from subduction zones are usually enriched in Th with respect to Ta (Pearce & Peate, 1995) compared to those from the within-plate environment. This condition occurs because the volcanic derived from subduction zones obtain contribution of various components such as mantle wedge, oceanic crust, sediments, fluid and hydrous melts that added to magma generated by subduction (Hawkesworth *et al.,* 1991; 1993; 1997; Pearce & Parkinson, 1993; Pearce & Peate, 1995). In term of the mobile character of elements, the HFSE as well as HREE (Heavy Rare Earth Elements) is known as relatively immobile elements or also called as compatible elements that usually is not mobilized by fluids or by the downgoing slab. These elements pattern reflects the origin environment of the magma and, therefore, they are usually used as discriminant elements to identify the tectonic setting of volcanic. On the other side, the LILE, as well as Light Rare Earth Elements (LREE) are classified as incompatible elements that are very mobile and enriched by fluids.

The fluid derived by dehydration of down going oceanic slab plays an important role in elements transfer between the slab and arc-generated magmas (Tatsumi *et al.,* 1995) and hence, the arc-derived volcanic should be higher on LILE/HFSE ratio compared to the within-plate setting. But, of course, there are some exceptions to the previous statements. In the case of Th, the element is an HFSE, but in arc environment Th shows incompatible element character (Pearce & Peate, 1995). Probably due to its extremely low solubility in subduction zone (Balley & Ragnasdottir, 1994), Th is much enriched in the arc environment, and the enrichment is considered to be derived from the sediment components of the down going slab. This interpretation could explain the well documented increasing of Th with respect to Ta in arc magmas (Hawkesworth *et al.,* 1997). Even though the clear mechanism that responsible for the enrichment of Th with respect to Ta in arc-magmas is still controversial, the fact remain that arc-generated magmas show a higher Th/Ta ratio than magmas generated in within-plate or in continental volcanic zones. This fact will be used to reveal the tectonic origin of the Pasaman volcanic, whether they are derived from magmas in arc environment, or from the active continental margin (ACM) setting. If Sumatra belongs to continental block as a homogeneous segment, so that the geochemical signatures of Pasaman volcanic must show only one pattern indicating continental or within-plate origin.

GEOCHEMICAL SIGNATURES OF THE PASAMAN VOLCANIC

Fifteen selected samples of the Pasaman volcanic that collected from the Tertiary Undifferentiated type are analyzed for major-, trace- and Rare Earth Elements (REE). The analytical data of major elements is given in the Table 1.

Table 1. Major elements analytical results of the Pasaman volcanic

Oxide (%)	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	Total
SAMPLE											
PS-3A	56,73	18,36	7,73	0,139	3,36	7,38	3,64	1,40	0,755	0,19	99,68
PS-3B	56,79	17,54	7,58	0,148	3,20	7,42	3,34	1,57	0,702	0,16	98,45
PS-4A	57,91	17,71	7,50	0,142	3,00	6,17	3,43	1,72	0,741	0,18	98,50
PS-4B	58,68	17,55	7,35	0,135	2,74	6,34	3,22	1,96	0,718	0,14	98,83
PS-05A	50,24	16,81	9,46	0,177	8,37	10,51	2,44	0,52	0,873	0,14	99,54
PS-05B	59,59	16,70	6,74	0,131	3,71	6,64	3,02	2,09	0,686	0,17	99,48
PS-06	57,54	18,54	6,94	0,160	2,53	6,67	3,70	1,67	0,661	0,26	98,67
PS-19C	56,85	18,22	8,15	0,157	3,43	7,07	3,35	1,17	0,789	0,17	99,36
PS-19F	65,60	16,13	3,40	0,071	2,27	4,00	4,29	2,47	0,510	0,18	98,92
PS-30	67,51	15,63	3,27	0,043	2,09	2,97	3,86	3,29	0,479	0,16	99,30
PS-41	58,25	16,55	7,05	0,127	4,03	7,12	2,93	1,84	0,665	0,14	98,70
SD-06A	76,45	10,72	2,02	0,030	0,73	0,27	1,46	6,01	0,331	0,11	98,13
SD-06B	52,28	18,52	9,62	0,313	3,10	8,86	2,88	0,92	0,866	0,16	97,52
PT-02	51,23	17,55	8,92	0,162	7,14	9,31	3,04	1,04	0,880	0,24	99,51
BJ-01C	78,35	12,11	0,80	0,013	0,11	0,03	0,50	4,44	0,112	0,02	96,49

The above table shows that the Pasaman volcanic are dominated by intermediate rocks with three samples having basaltic composition and four samples belong to rhyolitic rock type. These compositions are typical for volcanic derived from subduction zones. Most of the rocks belong to Medium-K type and only one sample is plotted between High-K and Shoshonitic zone (Figure 5).

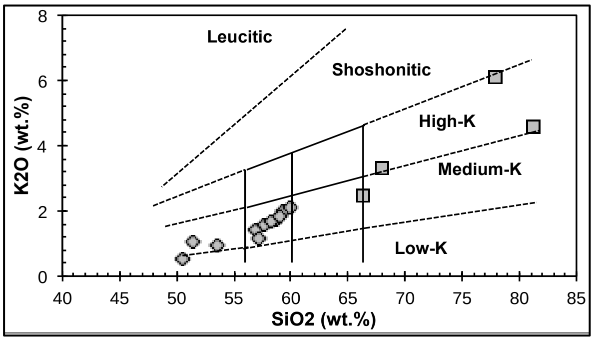

Figure 5. Most of the Pasaman volcanic belong to Medium-K type and dominated by andesitic composition (after Le Bas, 1986).

Besides that, almost all rocks show calc-alkaline affinity and only one basalt sample is plotted in tholeiitic field (Figure 6). This affinity is in line with the facts that the Pasaman volcanic is dominated by andesitic rocks with medium-K character.

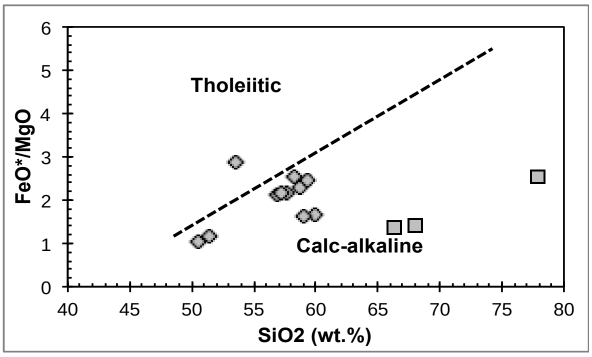

Figure 6. Almost all of Pasaman volcanic show calc-alkaline affinity and only one basalt is plotted in the tholeiitic field (after Miyashiro, 1974).

The analytical results of the Pasaman volcanic for selected trace elements are demonstrated in the Table 2. As mentioned above, that the trace elements, particularly Th, Ta and other HFSE will be used to analyze the Pasaman volcanic in order to reveal their tectonic origin. The discriminant diagram proposed by Gorton and Schandl (2000) using Ta/Yb versus Th/Yb after they revised from Pearce (1983) can be used to identify the tectonic origin of volcanic, whether they belong to oceanic arc or active continental margin (ACM) or within-plate volcanic zone (WPVZ) or belong to within-plate basalt (WPB).

Plotted the Pasaman volcanic in the diagram gives a distribution of samples in the area between ACM and Oceanic Arc, where seven samples are in the field of ACM, and the rest spreads along the line between ACM and Oceanic Arc towards the Arc zone (Figure 7). No samples represent the WPVZ and WPB tectonic setting. This evidence indicates that Pasaman volcanic is derived not only from ACM tectonic setting, but there are also samples originated from oceanic or island arc tectonic environment. It means Sumatra is not composed only of continental material but there is also oceanic or island arc segment.

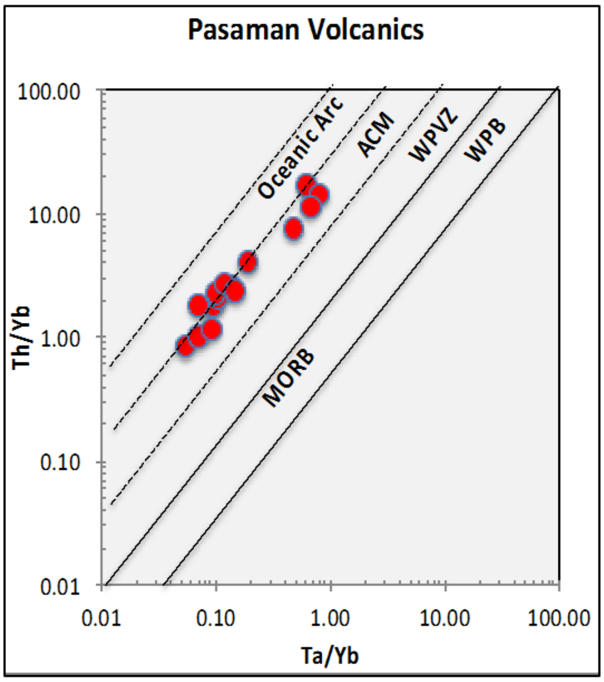

Figure 7. Plotted Pasaman volcanic in the diagram Ta/Yb versus Th/Yb showing that the rocks derived from ACM and Oceanic Arc tectonic settings (after Pearce, 1983).

Gorton and Schandl (2000) developed other discriminant diagram using directly Th/Ta ratio versus Yb in ppm, and they found out that the specific field for each tectonic setting can be determined. The Mid Oceanic Ridge Basalt (MORB) and WPB field has Th/Ta ratio less than

1, while for WPVZ the ratio values between 1-6, for ACM >6-20 and for Oceanic Arc >20-90.

Plotted the Pasaman volcanic in the diagram gives a distribution of samples in the field of ACM and Oceanic Arc (Figure 8). This result is very similar to the point distribution in the diagram Ta/Yb versus Th/Yb (Figure 7), even giving more clear separation between the two tectonic settings. The figure 8 shows that there are five samples of the Pasaman volcanic derived from Oceanic Arc tectonic setting while the others derived from ACM environment. Identification of rocks derived from oceanic arc or island arc tectonic setting seems also can be done by plotting the rocks in spider diagrams. For that purpose, selected trace elements including LILE and HFSE of the samples are normalized to MORB, plotted in spider diagrams and then find out a certain pattern that unique and different from other samples.

Table 2. Analytical results of selected trace elements of the Pasaman volcanic

In ppm	Ba	Rb	Th	K	Nb	Ta	La	Ce	Sr	Nd	P	Sm	Zr	Hf	Ti	Tb	Y	Tm	Yb
Sample																			
PS-3A	321	43	4,7	11617,021	4	0,2	17,2	35,3	366	17,5	829,58	4,2	123	3,5	4525,46	0,7	25	0,41	2,6
PS-3B	263	47	5,5	13027,66	3	0,2	14,4	30,6	311	17,0	698,59	4,2	115	3,5	4207,78	0,8	29	0,47	3,0
PS-4A	400	52	6,5	14272,34	5	0,3	19,5	41,5	307	20,1	785,92	4,8	166	4,7	4441,55	0,8	28	0,48	3,1
PS-4B	372	65	7,2	16263,83	4	0,3	19,6	40,2	292	20,1	611,27	4,7	162	4,5	4303,69	0,9	30	0,50	3,1
PS-05A	172	13	1,7	4314,8936	3	0,1	10,4	21,7	349	12,0	611,27	3,1	76	2,1	5232,75	0,6	21	0,33	2,1
PS-05B	422	60	8,0	17342,553	5	0,4	20,2	37,0	356	15,8	742,25	3,4	120	3,3	4111,88	0,6	19	0,30	2,0
PS-06	380	48	6,1	13857,447	5	0,3	21,6	41,9	466	19,9	1135,21	4,3	139	3,7	3962,03	0,7	22	0,37	2,4
PS-19C	244	28	2,5	9708,5106	3	0,2	11,5	24,8	358	13,7	742,25	3,5	110	3,0	4729,26	0,7	23	0,38	2,4
PS-19F	543	62	6,8	20495,745	6	0,4	18,7	37,0	804	15,6	785,92	2,8	153	4,1	3056,94	0,3	9	0,14	0,9
PS-30	580	97	13,9	27300	7	0,5	17,2	35,1	682	13,6	698,59	2,4	146	3,9	2871,12	0,3	8	0,12	0,8
PS-41	349	54	6,0	15268,085	4	0,3	16,9	29,6	392	15,7	611,27	3,8	101	2,9	3986,00	0,6	21	0,33	2,2
SD-06A	392	184	5,6	49870,213	5	0,3	10,3	20,3	351	7,8	480,28	1,5	71	2,1	1984,01	0,2	4	0,07	0,4
SD-06B	291	16	2,3	7634,0426	3	0,2	11,6	23,8	454	12,4	698,59	3,2	83	2,3	5190,80	0,6	21	0,33	2,1
PT-02	310	24	5,3	8629,7872	5	0,3	20,4	40,5	463	19,2	1047,89	4,2	106	3,0	5274,71	0,7	21	0,35	2,2
BJ-01C	662	199	14,0	36842,553	8	0,8	14,9	26,0	15	8,0	87,32	1,5	77	2,4	671,33	0,2	9	0,18	1,2

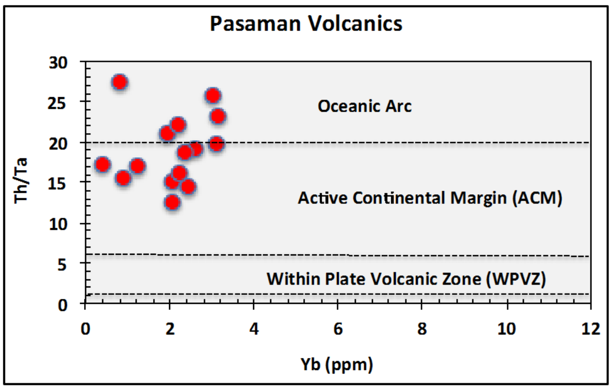

Figure 8. Plotted Pasaman volcanic in the diagram Yb (ppm) versus Th/Ta showing clear separation of five samples Oceanic Arc from other ACM derived samples (after Gorton & Schandl, 2000).

Plotted five samples derived from oceanic-arc tectonic setting in spider diagrams show a unique and different pattern compared to ACM-derived rocks, where Th points are always higher than Ba

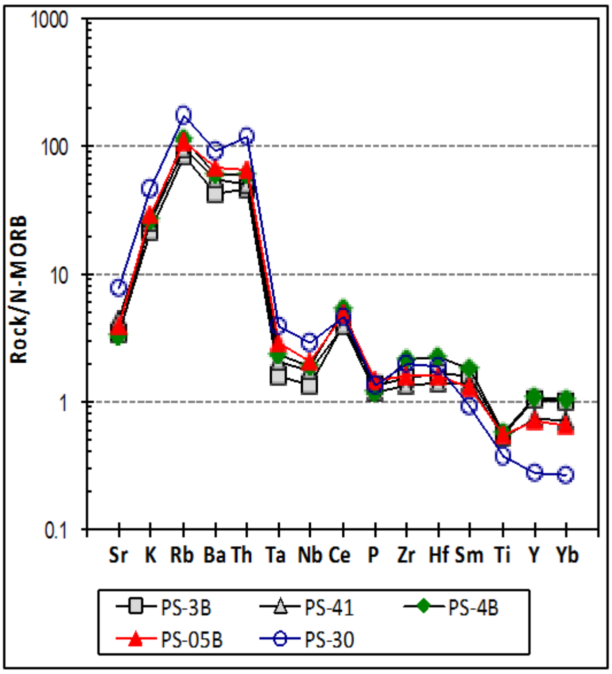

Figure 9. Spider diagrams of five Pasaman volcanic derived from oceanic arc showing specific pattern where points of Th are always higher than Ba.

(Figure 9). It is in line with inference above that the magmas generated in arc are always enriched on Th compared to other tectonic setting.

All samples in Figure 9 reflect similar pattern from LILE in the left until to HFSE in the right side, except one sample (PS-30) that showing significant depletion on Y and Yb. These depletions are probably related to its higher concentration of LILE, Th, Ta and Nb compared to other samples or the rock contain significant amount of K-feldspar and acid plagioclase.

The other samples that based on the previous diagram classified as rocks derived from ACM tectonic setting (Figure 8) are also plotted in spider diagrams. The results reflect that all samples have the similar pattern where points of Th are always lower than Ba (Figure 10, 11), except one sample (BJ-01C) that having similar pattern with the rocks derived from arc environment (Figure 10).

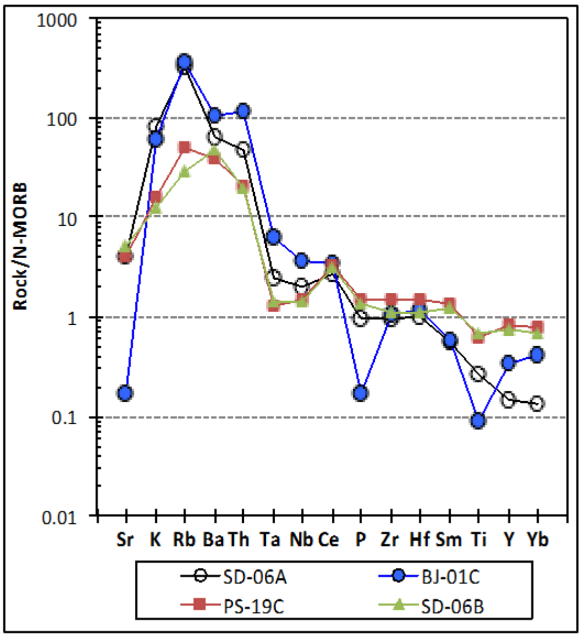

Figure 10. Plotted four samples of Pasaman volcanic showing different pattern compared to arc-derived rocks with points Th lower than Ba, except for sample BJ-01C.

Although the BJ-01C sample has a similar pattern with the arc-derived rocks, but the rock is significantly rich in K, Rb, Ba, Th, Ta, and Nb, as well as significantly depleted on Sr, P and Ti. It looks like that the rock probably was derived from magma in the arc tectonic setting, but influenced by certain process or mechanism.

One of ACM-derived rocks (SD-06A) also shows significantly depleted on Ti, Y, and Yb, but the rock also is significantly rich in LILE, Th, Ta and Nb as observed in the sample PS-30 in the arc-derived group. The similar pattern is also shown by sample PS-19F (Figure 11).

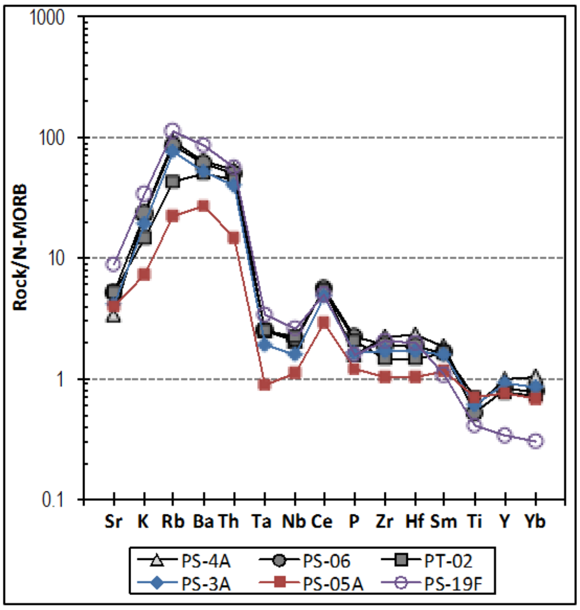

Figure 11. Plotted six samples of Pasaman volcanic derived from ACM tectonic setting showing points of Th lower than Ba.

All plotted samples derived from ACM tectonic setting in figure 10 and 11, actually can be distinguished into two different patterns, particularly in a relation between Rb and Ba in their spider diagrams. The first pattern is characterized by rounded relation line from Rb to Th via Ba where the highest point is on Ba (sample SD-06B in the figure 10, also samples PS-05A and PT-02 in the Figure 11). All three samples have the higher content of Ba than Rb or Th. The second pattern representing the seven other ACM-derived samples show straight descending line due to a higher content of Rb than Ba and Th. It looks like that the ACM setting has two different environments where one setting is very influenced by fluids triggering enrichment on Rb, while the other ones is not.

Based on the above discussion, it is clear that the geochemical signatures of the Pasaman volcanic deliver evidences that the volcanic are derived

Table 3. Analytical result of REE for the Pasaman volcanic.

In ppm Sample	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
PS-3A	17,2	35,3	4,17	17,5	4,2	1,24	4,1	0,7	4,2	0,9	2,8	0,41	2,6	0,42
PS-3B	14,4	30,6	3,78	17,0	4,2	1,21	4,5	0,8	4,7	1,0	3,1	0,47	3,0	0,48
PS-4A	19,5	41,5	4,87	20,1	4,8	1,28	4,7	0,8	4,9	1,0	3,2	0,48	3,1	0,50
PS-4B	19,6	40,2	4,77	20,1	4,7	1,24	4,8	0,9	5,0	1,0	3,2	0,50	3,1	0,50
PS-05A	10,4	21,7	2,66	12,0	3,1	1,08	3,4	0,6	3,5	0,8	2,2	0,33	2,1	0,32
PS-05B	20,2	37,0	4,05	15,8	3,4	1,03	3,3	0,6	3,1	0,7	2,0	0,30	2,0	0,32
PS-06	21,6	41,9	4,85	19,9	4,3	1,34	3,9	0,7	3,8	0,8	2,5	0,37	2,4	0,40
PS-19C	11,5	24,8	3,10	13,7	3,5	1,09	3,7	0,7	3,9	0,8	2,5	0,38	2,4	0,40
PS-19F	18,7	37,0	4,05	15,6	2,8	0,83	2,2	0,3	1,7	0,3	1,0	0,14	0,9	0,14
PS-30	17,2	35,1	3,75	13,6	2,4	0,70	1,8	0,3	1,5	0,3	0,8	0,12	0,8	0,13
PS-41	16,9	29,6	3,80	15,7	3,8	1,13	3,6	0,6	3,6	0,7	2,3	0,33	2,2	0,35
SD-06A	10,3	20,3	2,14	7,8	1,5	0,35	1,1	0,2	0,9	0,2	0,5	0,07	0,4	0,06
SD-06B	11,6	23,8	2,87	12,4	3,2	1,06	3,3	0,6	3,5	0,7	2,2	0,33	2,1	0,32
PT-02	20,4	40,5	4,65	19,2	4,2	1,32	4,1	0,7	3,9	0,8	2,4	0,35	2,2	0,34
BJ-01C	14,9	26,0	2,53	8,0	1,5	0,32	1,2	0,2	1,5	0,3	1,0	0,18	1,2	0,21

from two different tectonic settings, namely island arc and ACM. In other word, it indicates that Sumatra is not an homogeneous segment of Gondwana derived continental blocks. It is also in line or strengthens the evidences from volcanic in Lampung, Bengkulu and Central Sumatra reported by Zulkarnain (2011, 2012, 2014) that concludes Sumatra consists of island-arc segment in the west and continental segment in the east.

It is also necessary to find out whether such discriminant patterns in the spider diagrams can also be found in the spider diagrams of REE. The analytical result of the Pasaman volcanic for REE is shown in the Table 3.

As well as the selected trace elements in the previous spider diagrams, the REE consists also of incompatible and compatible elements. The left side elements in the spider diagrams are incompatible elements, while those in the right side are compatible elements. The REE contents of the samples are normalized to MORB before plotting in their spider diagrams.

Six samples of the Pasaman volcanic derived from oceanic arc are plotted in the first REE spider diagrams (Figure 12), while the other ACM-derived rocks are plotted in the second spider diagrams (Figure 13).

In the figure 12, it can be seen that all the rocks are richer on LREE (La is the most incompatible ones) and each line is going down towards HREE (Lu is the most compatible element). But, all six samples show different patterns where two samples (PS-3B and PS-4B) have similar HREE concentration with MORB, while the other four samples are depleted on HREE compared to MORB, even two of them extremely depleted on HREE (PS-30 and BJ-01C). Based on the pattern in the REE spider

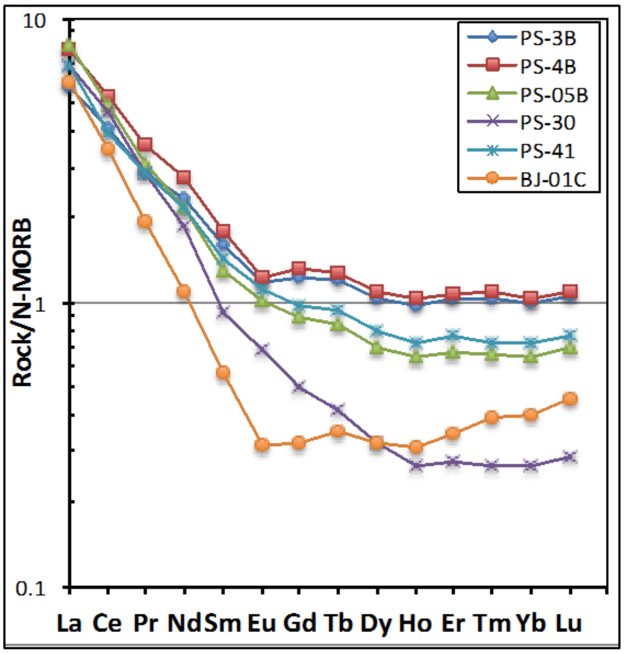

Figure 12. Plotted six samples arc derived Pasaman volcanic showing no specific pattern.

diagrams (Figure 12), it is concluded that REE spider diagrams cannot be used to identify the tectonic setting from where volcanic derived.

As observed in the figure 12, the spider diagrams of ACM-derived rocks in Figure 13, reflect also no specific pattern. All of the samples are rich on LREE and then the line is going down to Eu and after that extending slowly parallel to the line of MORB composition. This pattern is similar to two samples (PS-3B and PS-4B) of the arc-derived rocks in the figure 12. Besides that, one sample (PS-19F) demonstrates extremely depletion on HREE that is very similar to some samples of the arc-derived group. Hence, the spider diagrams of REE cannot be used to identify the tectonic setting of volcanic.

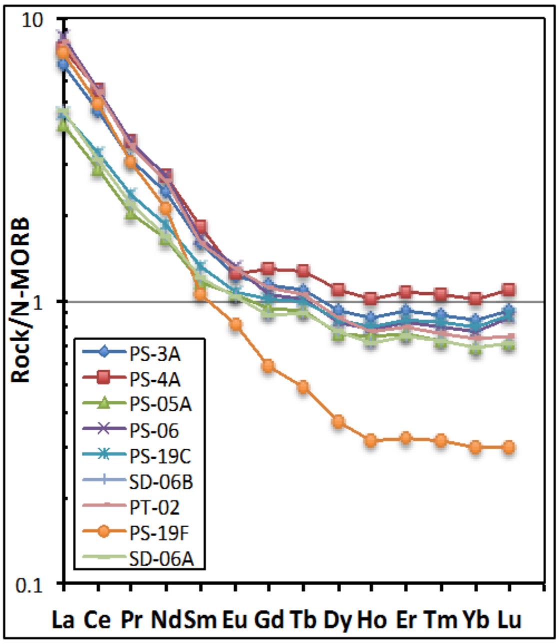

Figure 13. Plotted nine samples ACM derived Pasaman volcanic showing also no specific pattern.

CONCLUSION

As discussed at the beginning of this paper, many authors have written and drawn that Sumatra is composed of two continental blocks derived from Gondwana and continental fragments that accreted to the margin of Sundaland. It is implicitly interpreted that Sumatra is a homogeneous segment of continental block serving as continental margin of Eurasia. Many volcanic are distributed and crop out along western side of the island and based on their geochemical signatures, it can be revealed from which tectonic setting the volcanic derived. Hence, the geochemical signatures of the Pasaman volcanic can give information about it.

Plot of the Pasaman volcanic using the discriminant diagrams of Ta/Yb versus Th/Yb and Yb (ppm) versus Th/Ta give strong evidences that the Pasaman volcanic is derived from two different tectonic settings, where five samples were derived from oceanic-arc tectonic setting and ten samples were derived from active continental margin (ACM) setting. The two different tectonic settings can be traced also through specific pattern in their selected trace elements spider diagrams, while their REE spider diagrams cannot be used to identify tectonic setting from which the volcanic derived. Finally, it can be concluded that Sumatra is not a homogeneous segment of Gondwana derived continental blocks, but probably the island consist of two different segments, namely arc- and continental segments. It is in line with geochemical evidences that reported by Zulkarnain (2011, 2012, 2014) based on volcanic in Lampung, Bengkulu and Central Sumatra.

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