
Open access

https://jrisetgeotam.lipi.go.id/index.php/jrisgeotam

RISET
Geologi dan Pertambangan
Geology and Mining Research

Riset Geologi dan Pertambangan (2024) Vol.34, No.1, 25–40, DOI: 10.55981/risetgeotam.2024.1279

Research article

Geochemical characteristics of volcanic rocks in the Karaha–Talagabodas Field related to the Galunggung Volcano

Andrie Al Kausar[1], Iwan Setiawan[1], Anita Yuliyanti[1,2], Lediyantje Lintjewas[1,3], Jakah[1], Wawan Herawan[1]

[1]Research Center for Geological Resources - BRIN, Bandung, Indonesia 40135
[2]Gadjah Mada University, Yogyakarta, Indonesia 55281
[3]National Taiwan Normal University, New Taipei City, Taiwan 244014

Keywords:
Karaha-Talagabodas
geochemistry
volcanic rocks

Corresponding author:
Andrie Al Kausar
Email address: andrie.kausar@gmail.com

Article history
Received: 07 November 2023
Revised: 27 Maret 2024
Accepted: 24 April 2024

ABSTRACT

The Karaha-Talagabodas field is located on the east side of the ancient Bandung-Garut caldera and adjacent to the Galunggung volcano in West Java, Indonesia. Geochemical analysis, including major, trace and rare earth elements, conducted by fusion ICP-MS to find out the different composition of volcanic rocks in the two regions that are separated by approximately 10 km. The volcanic rocks of the Karaha-Talagabodas field were composed of pyroxene andesite, andesite basaltic, basalt, highly altered pyroclastic and tuff breccia. The identified alteration minerals are indicated by the presence of kaolinite, halloysite, silica, sericite, and chlorite. Geochemically, these volcanic rocks contain SiO_2 variable (49.94%-62.27%), Na_2O (3.02%-3.83%) and K_2O (0.46%-1.78%). Based on the major element diagram of rock chemistry (Na_2O+K_2O vs SiO_2). It shows rocks consisting of calc-alkaline for andesite from Karaha basalt, basaltic andesite and andesite formed in tholeiitic environments on Talagabodas volcanic rocks. Trace element data for host volcanic rocks are provided by this study to identify the magmatic arc system and distribution of subduction components. The normalized REE diagram of N-MORB shows the similarity of the pattern of all Talagabodas volcanic rocks, only Karaha andesite rocks show slight REE enrichment and europium depletion.

INTRODUCTION

The geology of Indonesia is dominated by volcanic arcs which consist of 147 volcanoes (Siebert et al., 2010) and West Java Province has geothermal potential for approximately about 6.101 MWe is the biggest among other provinces from 29,543 MWe total resources of Indonesia (Ministry of Energy and Mineral Resources, 2015). In the West Java Sunda Arc segment, geothermal potential was found to be associated with volcanoes and parallel to subduction. Volcanic products are the result of the subduction process Indo-Australian oceanic plate beneath the Eurasian continental plate and is closely related to the existing geothermal system in West Java (Setiawan et al.,2017). The Garut area, especially the eastern Garut, consists of volcanic rocks produced by an eruption, and there are several geothermal manifestations, including both rock alteration volcanic and hot springs (van Padang, 1951).

An ideal hydrothermal system basically consists of a heat source, some sort of underground water system to transport and sometimes store the heat (the reservoir), and a confining impermeable structure (the cap) (Figure 1). Conceptual models of geothermal systems provide an essential basis for the development of all reliable models of geothermal systems. This applies to a varying degree for different kinds of models, ranging from static volumetric models to dynamic models such as simple analytical models, lumped parametric models and detailed numerical reservoir models. This was already emphasized as early as by in their dissertation on numerical modeling of geothermal systems.

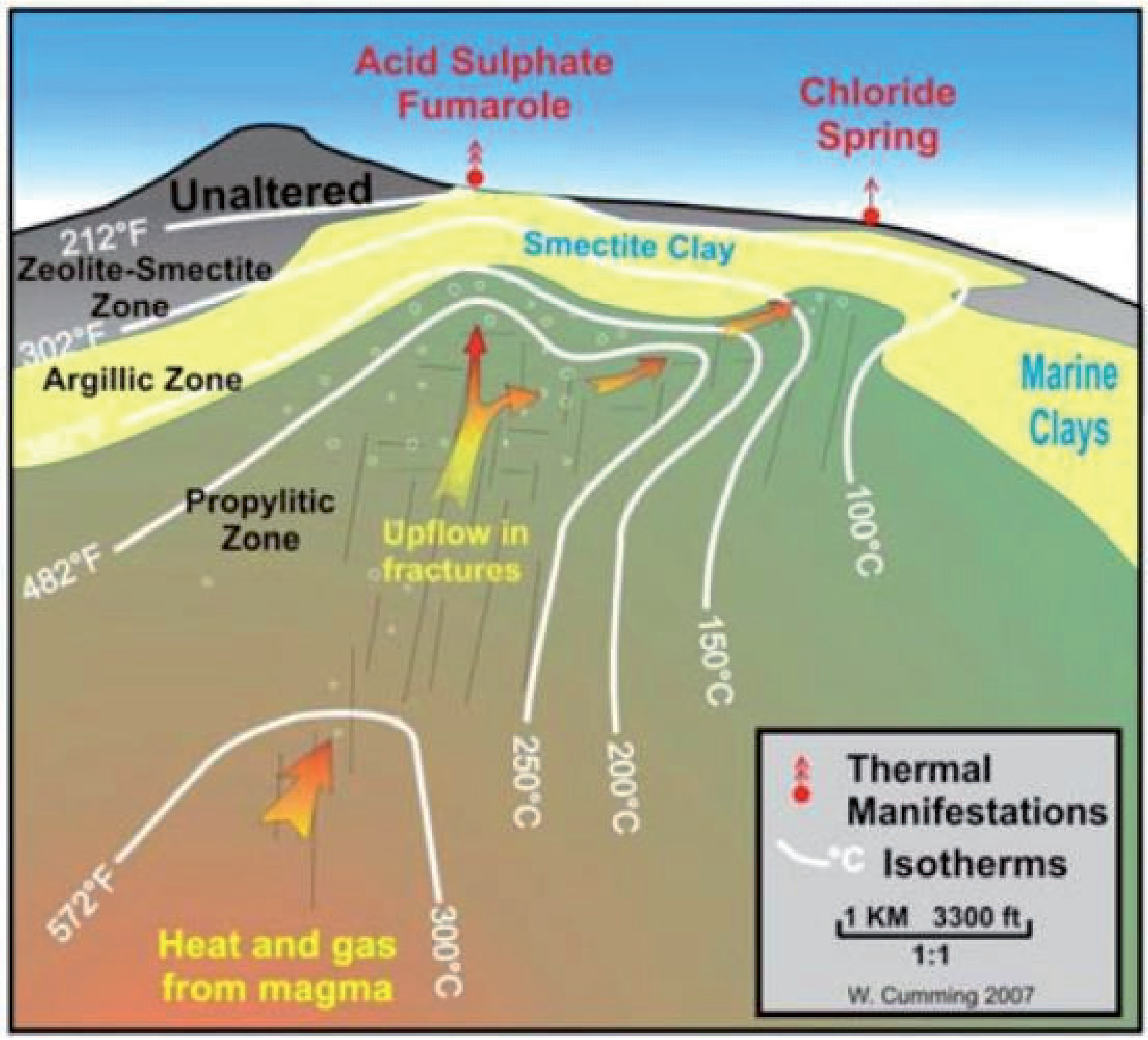

Figure 1. Conceptual model of a generalized geothermal system (redrawn from Cumming, 2009).

Based on tectonic and geological features, Java Island can be divided into three distinct areas, namely West Java, Central Java, and East Java (Clements et al., 2009; Clement and Hall, 2007). This research areas are located in the Bandung Zone and the Quaternary Volcanic Zone (van Bemmelen, 1949; Martodjodjo, 1984) where the northeast-southwest trending lineages were estimated from fault zones that formed the volcanic series Calancang, Mandala Wangi, Guntur, Kendang and Papandayan. The boundary between the Garut plain and the southern mountains is covered by Cikuray volcano. The eastern part of the Garut mainland is bounded by other Quaternary volcanic ranges (Cakrabuana, Sadakeling, Talagabodas, Galunggung and Karacak) (Figure 2).

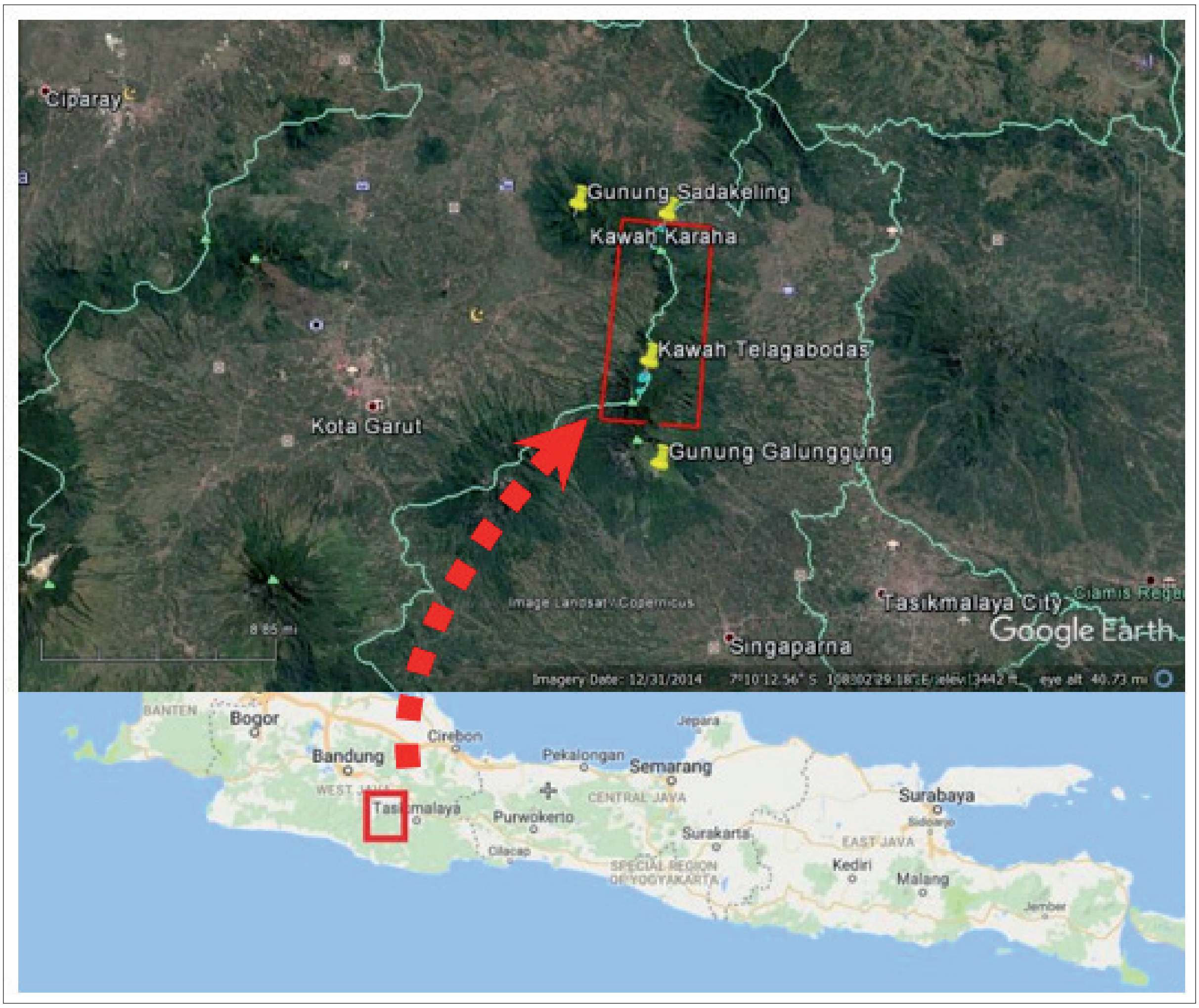

Figure 2. The location of research that located on the border Garut and Tasikmalaya.

The presence of volcanic igneous rocks in this study area which indicates an ongoing magmatic activity is the key to study the evolution of magmatic activity at certain times. The magmatic activities also have a close relationship with mineralization through the hydrothermal processes. The aim of this research is to determine the magmatic evolution and interpretation of its tectonic environment based on the geochemical analysis.

GEOLOGICAL SETTING

The study was conducted in two locations, Talagabodas and Karaha areas (Figure 3). The Talagabodas area and its surrounding area are dominated by strongly altered breccia rocks - totally altered, the estimated original rocks were tuff breccia. The altered breccia is grayish-reddish-white in color, and the matrix is altered to silica and clay (argillic) minerals (Figure 4). Some breccia tuffs whose fragments are still relatively fresh can be identified as fragments of gray andesitic - andesitic basaltic rocks, and there are other fragments in the form of tuffs. Andesitic lava is exposed in the vicinity of the bathing site, showing the solid sheet structure. Several observation sites within the area are former manifestation sites, and some are still active manifestations, generally in the form of solfatara/fumaroles, hot springs, warm ground, and mud pools. These sites generally show alteration of argillic rocks accompanied by sulfur deposits.

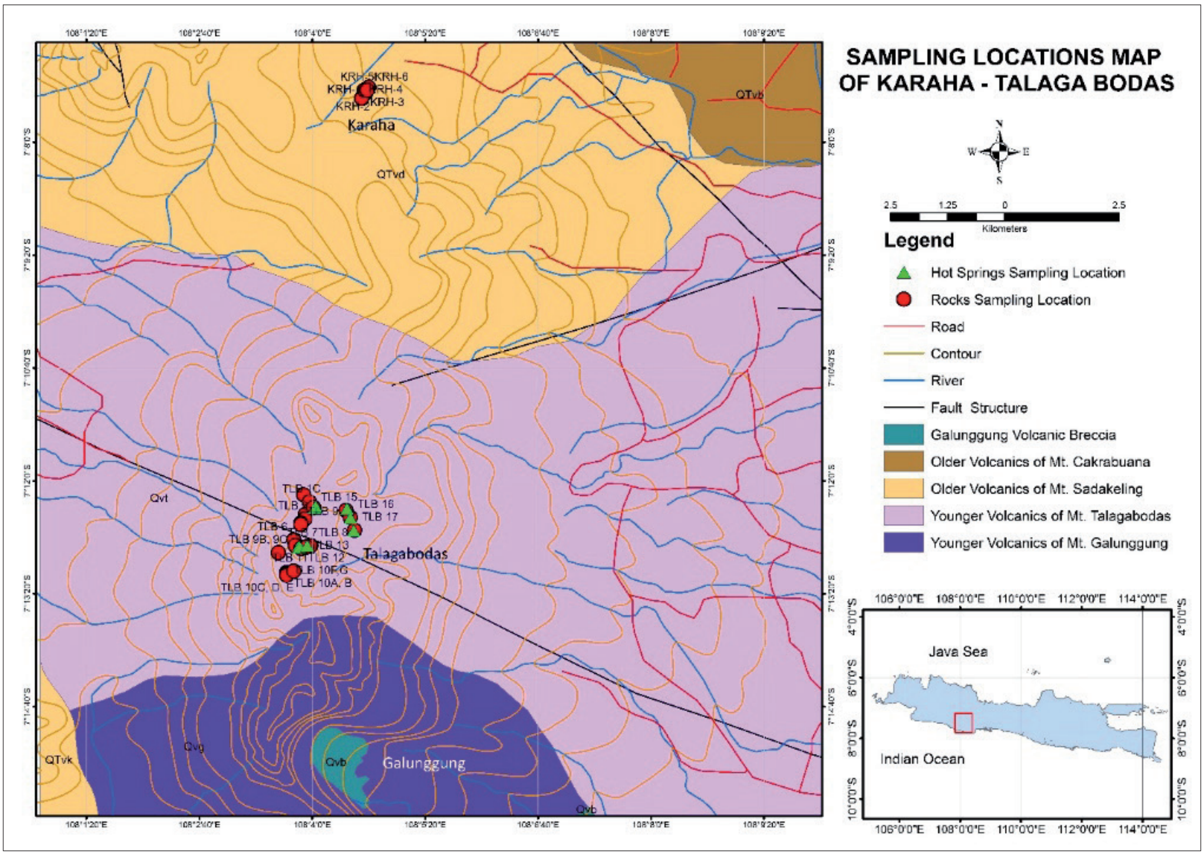

Figure 3. Sampling Locations map of Karaha – Talagabodas field which include in Geological map of Garut and Tasikmalaya sheet.

In the southwestern part of the Talagabodas crater wall, volcanic ash layers are less compact (easily separated), fine sand-sized components, and the black floor is in contact with an altered breccia, suggesting a fuel effect on the contact area. In the southern part of the crater wall, the dark gray andesitic lava was found; the position of the rock was thought to be on top of the tuff breccia crossed by fault.

In Talagabodas, solfatara is found with steam temperatures ranging from (77-90) ^{o}C and hot springs, almost all of which show a low degree of acidity (pH) = 1.8-2.7 (acidic) and temperature ranges from (43 - 59) ^{o}C and the surrounding tuff breccia is strongly altered - totally altered. In the southern part of the crater there is a mud puddle >2m in diameter emitting hot steam, probably >70^{o}C.

Figure 4. The outstretched strong total tuff breccia outcrop in Talagabodas, grayish white - reddish white, the fragments are altered into argillic (Fr) and the matrix (Mt) is altered (devitrification) into silica and reddish clay minerals (Lp). Fresh rock fragments in the form of basaltic andesite.

Kawah Saat is a part of the Talagabodas area that is one of the observation sites in the form of active solfatara (Figure 5). Geothermal activities in the form of solfatara are quite common and are spread around the crater. Volcanic sand deposits are often found around Talagabodas and Kawah Saat. The sand deposit is often found in line with the carbon layer, which is thought to be paleosoil. In some places, volcanic sandstone layers are often associated with crustal black iron oxide deposits (Figure 6). The active hydrothermal vent also appears to penetrate around the root structure of old trees that have died, forming sulfur-mixed clay deposits. The alteration rocks in the field are generally a matrix of breccia. Tuff material appears to be more strongly altered than fragile igneous rock, making fresh rock samples very difficult to obtain. Alteration in the field occurs as white-gray to blackish-gray alteration clay, some of which is associated with sulfur and blackish mafic minerals (Figure 7).

The rocks in the Karaha area are basically similar to Talagabodas, they consist of tuff breccias that have strong alteration - total alteration (Figure 8). Alteration is predominantly silica and argillic, resulting a grayish white to reddish gray. These breccia tuff fragments and matrices are generally altered. The fragments are altered to argillic while the matrix is altered to silica and argillic (white-reddish) and sometimes pyrite is found. Sometimes a fragment of breccia tuff is found which is weakly altered in the form of greenish-grey andesite. Fumaroles are more commonly found in this area than sulfate. The measured temperature of fumarole steam reaches 94°C. The hot spring is very rare and has a small source, indicating a neutral pH (pH = 7).

Figure 5. Location of geothermal manifestations which active solfatara around Kawah Saat.

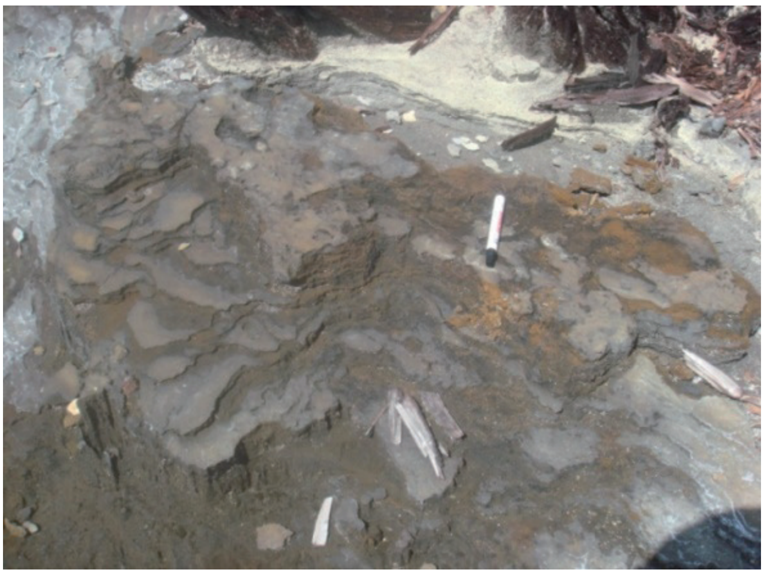

Figure 6. Volcanic sand deposits contain rich iron oxide crust at TLB 10.

METHODS

The initial stage of this research is to study secondary data from previous research results that that have been collected then the next step is to conduct field research for primary data collection in the form of geological observations, The samples taken from the field were analyzed using petrographic analysis using a polarizing microscope with a thickness of ±0.03 mm to determine the name and condition of rocks based on their texture, structure, and mineral composition. Subsequently, geochemical analysis of major and trace elements performed by using Fusion ICP-MS to find out how the different composition of volcanic rocks in the two regions (Karaha and Talagabodas). An amount of 1.5 to 2 grams of powdered samples sent to Activation Laboratories Ltd. (Actlabs), Canada and the result from analysis with LOI above 5% usually must be re-analyzed (or skipped) for alteration confirmation.

Figure 7. Clay outcrop at TLB 6.

Figure 8. The strong-total altered tuff breccia outcrop, grayish white - reddish gray, the fragment is altered into argillic (Fr) and the matrix (Mt) is altered into silica and reddish clay mineral (Lp). Some fresh rock fragments are basaltic andesite (Fb). This tuff breccia is sometimes found in sulfide minerals (pyrite).

RESULTS AND DISCUSSION

Petrographic Analysis

The purpose of petrographic analysis is to determine the name and condition of rocks based on their texture, structure, and mineral composition based on Williams, et al., (1954) and Ehler et al., (1982). The results of petrographic analysis of fresh rock samples show that the rocks are composed of pyroclastic breccia fragments in the form of igneous andesite - basalt, with breccia texture and structure. Characteristic rounded polygenic fragments, matrix-supported breccia, no cement magmatic matrix. Some rocks show the presence of xenoliths and in general plagioclase is altered to sericite and chlorite. Some samples analyzed are TLB-1A, TLB-12 and KRH-2D (Figure 9A, 9B and 9C).

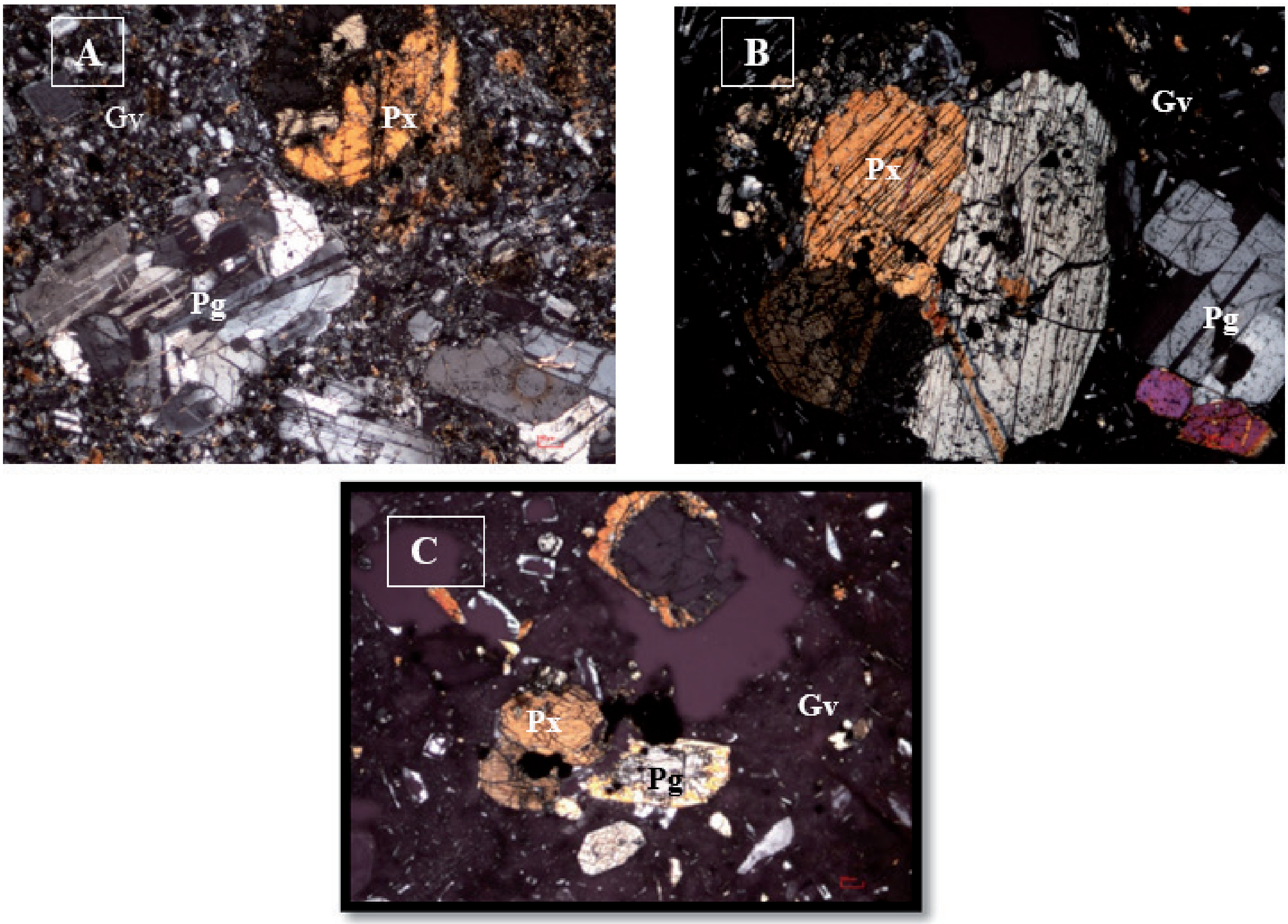

Figure 9. (a) Photomicrograph of basaltic andesite TLB-1A, **(b)** Andesite TLB-12, and **(c)** KRH-2D breccia tuff fragment found in Karaha, all thin sections show composition of volcanic glass (Gv), plagioclase (PG/andesine), pyroxene (Px).

Major Elements of Rock Samples

The geochemical composition is characterized by the content of oxide elements SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5. Geochemical analysis was performed on five samples collected from Talagabodas (TLB-1A, TLB-10C, TLB-1C, TLB-14) and one sample collected from Karaha (KRH-2D) by X-ray Fluorescence analysis (XRF analysis). The analytical result is summarized in Table 1. Sample from Talagabodas has SiO_2 contents ranging from 52.8 to 60.2 wt% (Fig. 9.a), which generally shows medium-K calc-alkaline to low-K calc-alkaline series (Figure 9.b). The Karaha sample has a SiO_2 content of 62.8 wt% (Figure 10.a), which is generally medium-K calc-alkaline series (Figure 10b).

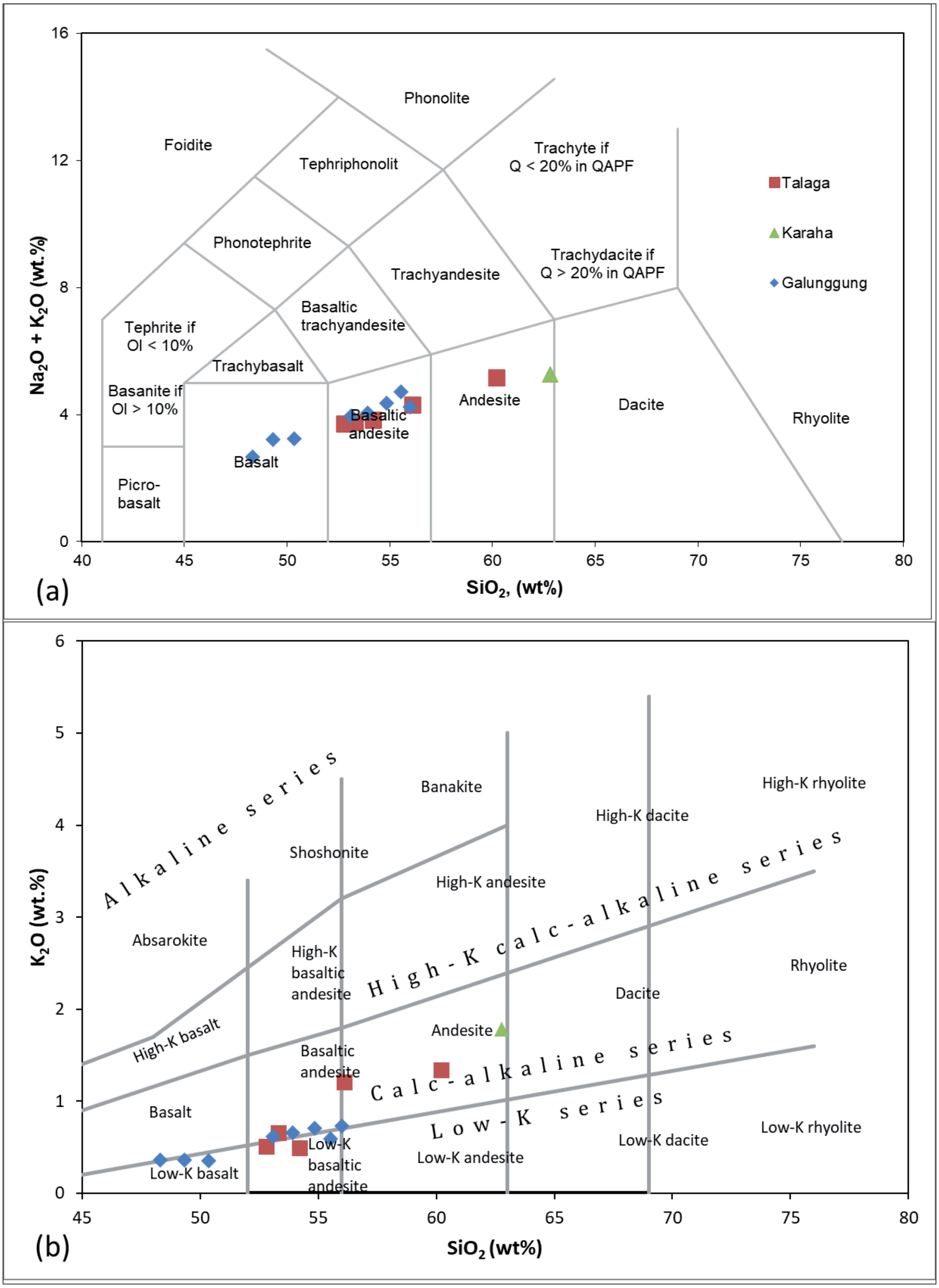

Figure 10. (a) Total alkalis vs. SiO_2 diagram (after Le Bas et al., 1986; Le Maitre, 2002) samples from Talagabodas, Karaha, and Galunggung. The line separating the sub-alkaline and alkaline regions was after Irvine and Baragar (1971). **(b)** Variation of K_2O vs. SiO_2 samples from Talagabodas and Karaha. Classification for K_2O–SiO_2 was after Gill (1981) and Peccerillo and Taylor (1976).

Based on the MgO content, the samples obtained from Talagabodas and Karaha are included in the low-Mg basalt (< 10% MgO) with the type of Low-K Low-Mg basalt because it has % K_2O 0.49-1.78 contents (Le bas et al., 1986). In the Harker diagram, these rocks appear to show a magma differentiation trend, as their SiO_2 has a positive correlation (Figure 11) with K_2O (0.49-1.78 wt.%), Na_2O (3.11-3.83 wt.%) and SiO_2 has a negative correlation with TiO_2 (0.58-1.03 wt.%), Fe_2O_3 (4.86-8.57 wt.%), MgO (1.80-3.62 wt.%) and CaO (4.91-9.25 wt.%). The plotted results of the main elements analyzed show a negative correlation pattern with SiO_2, which can be interpreted as the samples coming from the same magma. The positive correlation pattern of Na_2O and K_2O and the negative correlation of Fe_2O_3 and CaO show a regularity consistent with fractional crystallization where crystals are removed from the residual liquid as soon as they are formed, either by gravitational settling or floating. In this process, the bulk composition of the remaining liquid changes as crystals form and are removed (Holland & Powell, 2011).

Tabel 1. Summary of major elements geochemical data from research area.

Samples	TLB-1A	TLB-1C	TLB-10C	TLB-12	TLB-14B	KRH-2D
	Talagabodas	Talagabodas	Talagabodas	Talagabodas	Talagabodas	Karaha
SiO2	53,30	52,80	54,20	60,20	56,10	62,80
TiO2	0,89	0,98	1,03	0,75	0,94	0,58
Al2O3	19,60	20,00	19,00	17,80	17,30	16,60
Fe2O3	8,16	8,54	8,57	4,93	8,53	4,86
MnO	0,14	0,17	0,16	0,09	0,17	0,08
MgO	3,48	3,22	3,15	1,85	3,62	1,80
CaO	7,50	9,25	8,11	5,45	7,46	4,91
Na2O	3,11	3,20	3,34	3,83	3,10	3,48
K2O	0,66	0,51	0,49	1,34	1,21	1,78
P2O5	0,19	0,20	0,22	0,18	0,19	0,13
LoI	3,66	1,04	2,19	3,57	1,78	2,87
Total	100,4	99,89	100,5	99,96	100,4	99,39

The alkali-total iron-magnesium (AFM) diagram (Irvine and Baragar, 1971) is used to define magmatic affinity (Figure 12). The AFM diagram is a ternary plot where the concentrations of $Na_2O + K_2O$ (alkalis; A), FeO (F) and MgO (M) in the igneous rock have been recalculated after recalculation add up to 100%. If the rocks plotted belong to a magmatic series, they will define a trend and show a difference between two commonly observed trends: the Fe-enrichment trend (representing the differentiation of a tholeiitic magma) and the "straight-line trend" representative of the differentiation of a calc-alkalie magma. Therefore, this diagram can be used as a means of classifying different igneous rocks. AFM of most of the volcanic rock samples from Galunggung showed calc-alkaline composition with FeO_{total} composition: (0.93-9.24 wt%), Al_2O_3 (15.95-17.55 wt%) and MgO (2.29-10.60 wt%), but there are some samples showing tholeiitic composition. Volcanic samples in the Karaha and Talagabodas areas showed a calc-alkaline composition with total FeO_{total} (4.37-7.71 wt%), Al_2O_3 (17.30-20 wt%) and MgO (1.85-3.62 wt%).

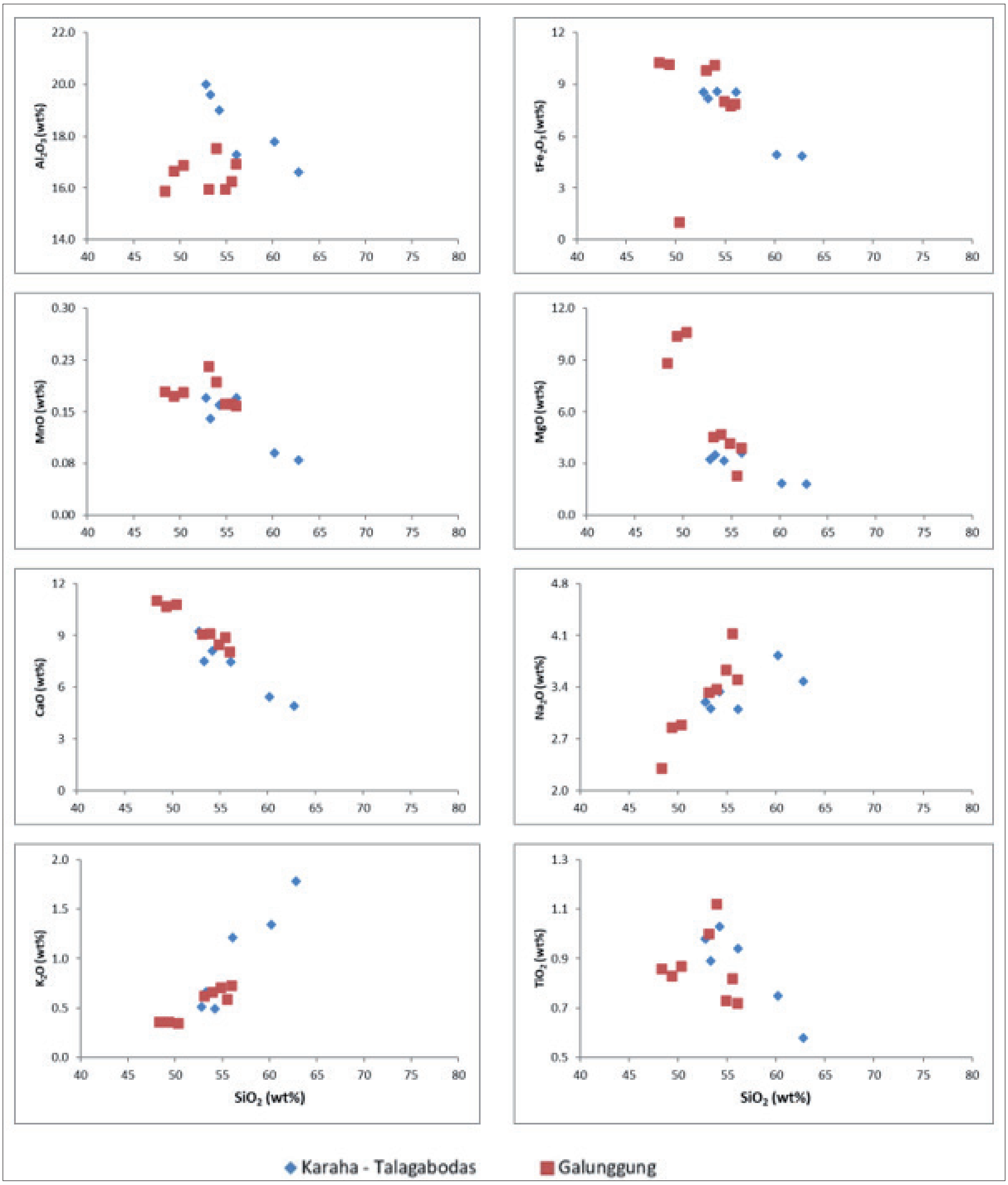

Figure 11. Plot of major elements vs SiO_2 (Harker's diagram) for the research sample from Talagabodas – Karaha and and compared with samples obtained from Galunggung Volcano.

Mullen (1983), using a trilinear diagram based on the comparison of the weight percent values of the compounds TiO_2, 10XMnO, and $10XP_2O5$, divides into four classifications, namely mid-oceanic ridge basalt, island arc tholeiite, island arc calc-alkaline basalt, oceanic island tholeiite, and oceanic island alkaline basalt. Based on the samples analyzed, the samples from Talagabodas and Karaha are related to the formation of island arc tholeiite (Figure 13).

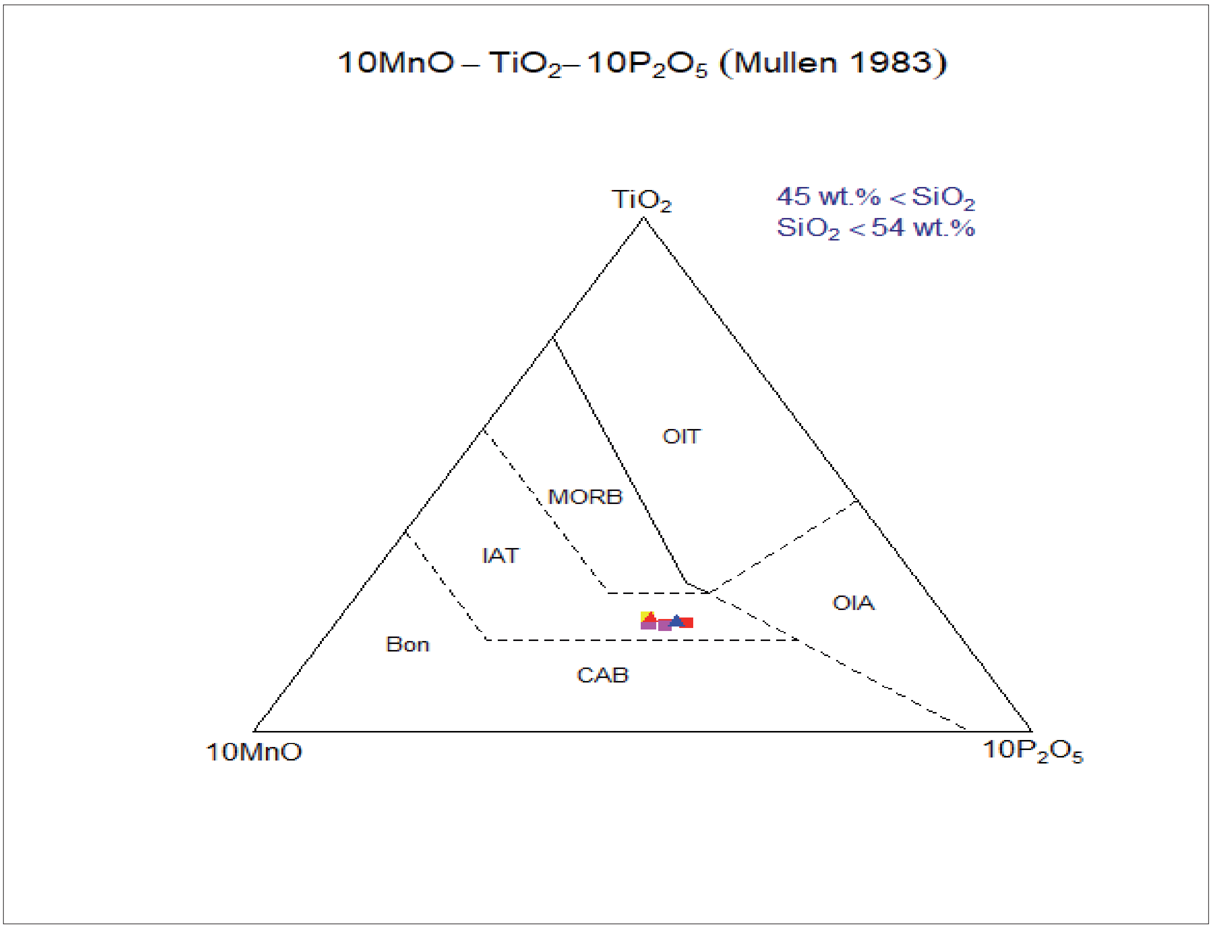

Figure 12. AFM diagram of Karaha – Talagabodas compared to Galunggung Volcano; origin of magma is based on Meschede (1986).

Trace Elements of Rocks

As a result of ICP-MS analysis, the Karaha volcanic rocks showed different REE patterns (Figure 14b) compared to the Talagabodas volcanic rocks. They are characterized by LREE enrichments, HREE depletions and slightly negative Ce anomalies. Their patterns of the primitive mantle normalized trace element diagram are similar and well comparable to those of the Talagabodas rocks. They also show subduction-related signatures with LILE (Ba, Th and K) enrichments and HFSE depletions, but to a lesser extent enrichments in Cs and Rb and depletions in Nb and Ta (Table 2).

Talaga – Karaha system

Major Elements

Major elements are considered as SiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, TiO_2 and P_2O_5. In terms of these, the most obvious distinction between the major magma series is one of increasing total alkali content in the sequence tholeiitic - calc-alkaline - high-K calc-alkaline - shoshonitic. The total alkali of Na_2O+K_2O content shows a range of 3.69-5.26 wt.% which is typical of axial island arc environment (Miyashiro, 1974).

Tabel 2. The summary of trace and rare earth elements of samples from research area.

Samples		TLB-1A	TLB-1C	TLB-10C	TLB-12	TLB-14B	KRH-2D
P	ppm						
Sc	ppm	21	24	23	16	21	13
Ti	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0,2
V	ppm	183	199	172	134	202	109
Cr	ppm	30	< 20	20	110	30	40
Mn	ppm						
Co	ppm	19	17	19	12	23	13
Ni	ppm	30	< 20	< 20	20	< 20	30
Cu	ppm	70	210	40	50	70	40
Zn	ppm	80	70	70	50	70	90
Ga	ppm	19	20	20	18	18	18
Rb	ppm	13	8	6	33	31	55
Sr	ppm	249	253	265	236	250	201
Y	ppm	25	24	25	26	22	268
Zr	ppm	110	81	111	161	137	140
Nb	ppm	4	3	4	5	5	3
Cs	ppm	0,6	< 0.5	< 0.5	2	2,2	3,7
Ba	ppm	156	127	126	280	217	342
La	ppm	9,2	7,5	7,8	11,4	10,4	86,2
Ce	ppm	20,6	17,4	18	25,7	22,7	76,2
Pr	ppm	2,68	2,35	2,5	3,33	2,84	24,5
Nd	ppm	12,4	11,7	11,8	15,3	12,7	119
Sm	ppm	3,5	3,5	3,3	4,2	3,4	32,3
Eu	ppm	1,22	1,23	1,24	1,16	0,98	13
Gd	ppm	4	4	3,8	4,3	3,7	41,3
Tb	ppm	0,7	0,7	0,6	0,7	0,6	7,3
Dy	ppm	4,2	4,3	4,1	4,6	3,7	46,6
Ho	ppm	0,9	0,9	0,9	0,9	0,8	9,9
Er	ppm	2,4	2,6	2,5	2,7	2,4	29,8
Tm	ppm	0,39	0,4	0,38	0,41	0,35	4,74
Yb	ppm	2,6	2,4	2,7	2,9	2,4	32
Lu	ppm	0,42	0,38	0,41	0,43	0,38	5,39
Hf	ppm	2,6	2	2,6	4	3,4	3,6
Ta	ppm	0,3	0,2	0,3	0,4	0,4	0,2
W	ppm	1	< 1	< 1	< 1	< 1	1
Tl	ppm	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0,2
Pb	ppm	6	6	< 5	6	8	10
Th	ppm	2,6	1,5	1,3	4,3	3,7	8,4
U	ppm	0,6	0,4	0,3	1,1	0,8	1,8

Harker diagrams were used to investigate the major element geochemical variations within the suite apparently co-genetic igneous rocks. K_2O generally behaves incompatibly within island-arc suites (Tatsumi and Eggins, 1995), and thus rocks that are genetically related should define linear trends with K_2O increasing progressively with increasing SiO_2 (Figure 12). The Al_2O_3 content of the volcanic rock samples is relatively uniform, ranging from 16.61% to 20%. In addition, a plot of Alkali Index (A.I) versus wt.% Al_2O_3 (Figure 12) is useful in distinguishing between tholeiitic and calc-alkaline basalts. The result shows that most of the rocks sampled are calc-alkaline basalts (Peccerillo and Taylor, 1976).

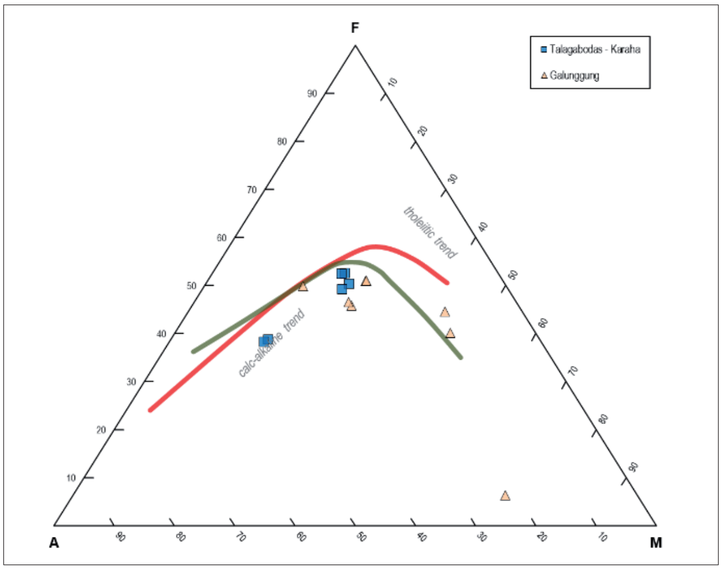

Figure 13. Analysis of determination Analysis of magma origin; The limits for T and CA are taken from Irvine and Barrager (1971).

Minor/Trace and Rare Earth Elements

The Nb/U-Nb and Ce/Pb-Ce diagrams show different geochemical signatures between the Talagabodas and Karaha volcanics. Figure 15 shows that the Talagabodas rocks are plotted together with the Karaha rocks within the domain of arc volcanic, Pearce and Peate (1995). This is due to Nb, one of the high field strength elements, with the record of depletion by the fluid effect in the magma region associated with dehydration of the subducting slab. Nb/U values reflect that the Talagabodas rocks showed an arc-like signature characterized by obvious HFSE depletions (Figure 13a). In contrast, Ce/Pb values show that the Talagabodas and Karaha rocks are in the range of arc volcanics. It shows that the enrichment in LILEs (such as Cs and Rb) and Pb in the Talagabodas rocks are not as high as those in the Karaha rocks (Figure 15). This reflects that the elements of Cs, Rb and Pb have different performances resulting from the fluid between these two stages. It seems that the subduction factors (e.g., LILE enrichments and HFSE depletions) are stronger in the Talagabodas than in the Karaha. This may indicate that the volcanics erupted in Karaha, mainly andesites, are typical subduction-related arc lavas. As for the volcanics in the Talagabodas with predominantly magmatic compositions, they have some elemental ratios with not only subduction-related but also intra-plate characteristics, indicating specifically different magma sources (Sun and McDonough, 1989).

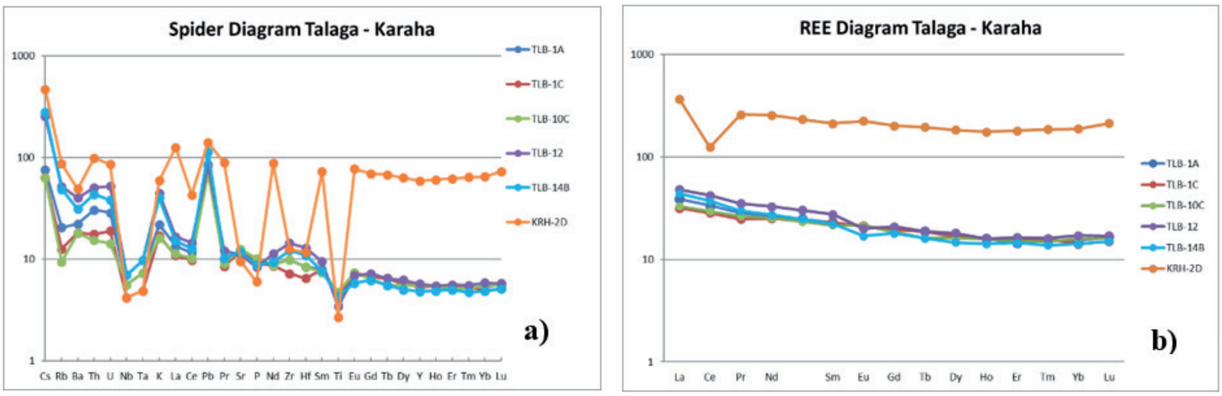

Figure 14. (a) Spidergrams, and **(b)** REE patterns normalized to primitive mantle and chondrite respectively from Talagabodas and Karaha, Primitive mantle values for normalization and Chondrite-normalized REE diagrams are from Sun and McDonough (1989).

Diagrams of rare earth elements normalized to N-Morb show similarities in the pattern of all Talagabodas volcanic rocks, but only the Karaha andesite rocks show enrichment of light rare earths and depressed europium (Eu) as fractional plagioclase crystallization (McDonough et al., 1992) The concentration of the elements in all the different rock samples is consistent, proving that the genetic relationships are differentiated by fractional crystallization. The diagram suggests that the Talagabodas and Karaha complexes have different magma sources.

Karaha & Talagabodas - Galunggung volcanic rock relations

Previous research stated that the Galunggung Mountain lava petrologically and geochemically consists of basalt (49-53% SiO_2), basaltic andesite (53-57% SiO_2) with a texture of porphyritic texture and medium-sized phenocrysts embedded in crystal or glass base mass.

Modal mineral analysis results indicate 15-40% phenocrysts dominated by plagioclase (±18%) and clinopyroxene (1.6%), but some lava samples lack clinopyroxene phenocrysts. Olivine is a mineral that is always present (1-4%) except in the Old Galunggung cryptodome rocks, where orthopyroxene dominates (up to 4%). Amphibole is absent from some Old Galunggung samples but is found in pyroclastic flow deposits. All minerals in the rocks of Mount Galunggung are thought to have crystallized at high temperatures (1000–1300) ^{o}C but under low pressure (Bronto, 1989).

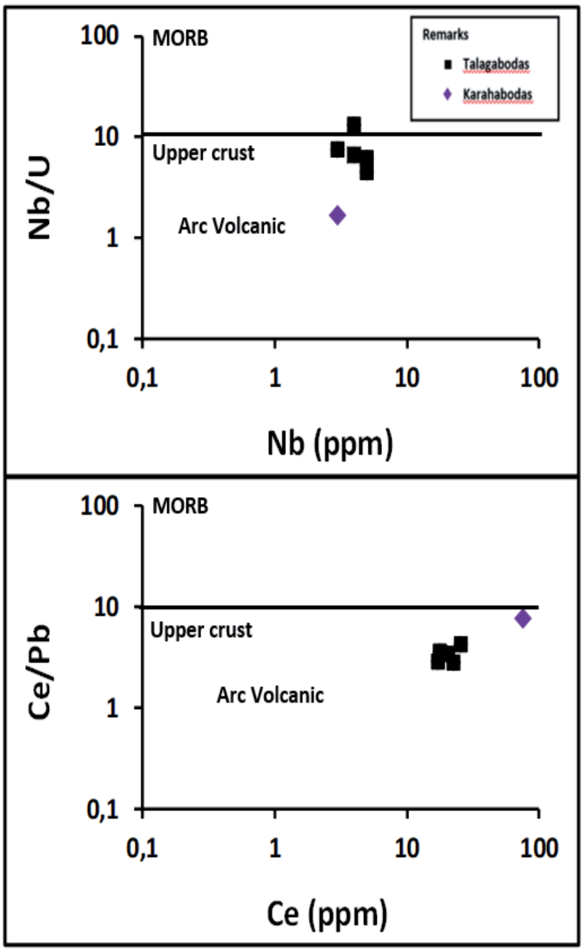

Figure 15. Nb/U vs. Nb diagram and Ce/Pb vs. Ce diagram. Averages value for MORB, Upper Crust and data for Arc volcanics are from Edwards et al., 1994, Hart and Reid (1991), Hofmann et al., 1986, Kersting and Arculus (1995), Mcdonough et al., 1994, Pearce and Peate (1994).

The volcanic rocks that compromising the Karaha – Telaga Bodas geothermal system are mostly composed of pyroclastic and epiclastic deposits. Andesitic to basaltic lava flows are widely distributed at depth, but were less commonly encountered in the wells (Moore, 2004). From several samples of volcanic rocks were obtained from Talagabodas area, the distribution of volcanic rocks in this area is spread from basaltic andesite to andesite with affinity in the form of low potassium series to calc-alkaline series, while in volcanic rocks that are the result of Galunggung volcanic activity spread from basalt to basaltic andesite with affinity in the form of low potassium series, so when comparing from these two areas it can be concluded that the further south the research area will have more basaltic rock type. Conversely, the rocks found in Karaha (north of the study area) are andesite, characterized by a higher SiO_2 value, as well as directly proportional to the increasing density of Na_2O and K_2O the more north the study area. In addition, the Karaha volcanics showed different REE patterns compared to Talagabodas volcanics. They are characterized by enrichments in LREE, depletions in HREE and slightly negative Ce anomalies. Their patterns in the primitive mantle normalized trace element diagram are overall similar and well comparable to those of the Talagabodas rocks. They also show subduction-related signatures with LILE (Ba, Th and K) enrichments and HFSE depletions. Based on the comparison data obtained for major elements, it is estimated that the subduction zone in the study area is shifting from south to north.

CONCLUSIONS

This study reports a dataset of Geochemical analysis including major, trace and rare earth elements of Volcanics rocks from the Karaha–Talagabodas fields and related to Galungggung. From volcanic rocks contain that obtained from field locations, shows rocks consisting of calc-alkaline for andesite from Karaha basalt, basaltic andesite and andesite formed in tholeiitic environments on Talagabodas volcanic rocks. The total alkali of $Na_2O + K_2O$ content shows a typical of axial island arc volcanics. The plotted results of the main elements analyzed show a negative correlation pattern with SiO_2, which can be interpreted that the samples come from the same magma. Trace elements characteristics from field areas are similar to those of arc magmas from modern subduction zones and represent a typical subduction-related feature. Based on the comparison data obtained for major elements only, it is estimated that the subduction zone from Galunggung to Karaha-Talagabodas is shifting from south to north.

ACKNOWLEDGMENTS

We acknowledge Ir. Sri Indarto, Ir. Sudarsono, and Ahmad Fauzi Ismayanto, M.T. for their contributions during the survey and discussions during manuscript writing. We thank the Director of the Research Center for Geotechnology for the research funding. This research material was collected during the geothermal research program at the Research Center for Geotechnology, funded in the Budget Implementation List for the 2012-2016 fiscal years. We appreciate the Garut Local Government (Garut) for giving permission to conduct research in their area. The Head of BKSDA and his staff who have provided permission and assistance during the conduct of this research; Mr. Asep AK as Head of the Cibatu regional Forestry Service who has given permission to carry out Magnetotelluric measurements in the Talagabodas area and surrounding areas. We also thank the editors and reviewers for the review and suggestion, which considerably improved our contribution.

REFERENCES

Arculus, R.J., & Powell, R., 1986. Source component mixing in the regions of ARC magma generation. *Journal of Geophysical Research, 91*.

Martodjodjo, R. W. van, 1949. The Geology of Indonesia, Vol. I.A. Government ,Print. Office, The Hague.

Budhitrisna, T., 1986. Peta Geologi Lembar Tasikmalaya, sekala 1: 100.000; 1308-4. P3G- KESDM.

Blatt, H. dan Ehlers E. G., 1982. *Petrology*, John Wiley & Sons Inc., New York.

Bronto, S., 1989. Volcanic Geology of Galunggung, West Java, Indonesia, PhD Thesis, Canterbury University, New Zealand: 490 p. (unpubl.).

Clements, B., Hall, R., Smyth, H. R., & Cottam, M. A., 2009. Thrusting of a volcanic arc: a new structural model for Java. *Petroleum Geoscience, 15*, p. 159-174.

Ehlers, E.G. dan Blatt, H., 1982, *Petrology Igneous, Sedimentary, and Metamorphic*. W.H. Freeman and Compay, San Francisco, 114-144.

Hall, R., & Clements, B., Smyth, H.R., Cottam, M.A., 2007. A new interpretation of Java's structure. *Proceedings, Indonesian Petroleum Association, Thirty-First Annual Convention and Exhibition, May 2007,* p. 131-176.

Holland, T. J. B., & Powell, R. (2011). An introduction to igneous and metamorphic petrology. John Wiley & Sons.

Irvine, T. N., & Baragar, W.R.A., 1971. A guide to the chemical classification of the common volcanic rocks. *Journal Earth Science, 8*, 523-548.

Iwan Setiawan., Sri Indarto., Sudarsono., Ahmad Fauzi., Anita Yulianti., Lediyantje Lintjewas., Andrie Al Kausar., and Jakah., 2017. Geothermal and Volcanism in West Java. IOP Conf. Series: Earth and Environmental Science 118 (2018) 012074. https://doi :10.1088/1755-1315/118/1/012074.

LeBas, M.J., LeMaitre, R.W., Streckeisen, A., & Zanettin, B., 1986. A chemical classification of volcanic rocks based on the total alkali silica diagram. *Journal of Petrology, 27*, 745-750.

Martodjojo, S., & Djuhaeni, 1996. Sandi Stratigrafi Indonesia. *Komisi Sandi Stratigrafi Indonesia*. IAGI, Jakarta, 36h.

McDonough, W.F., Sun, S.S., Ringwood, A.E., Jagoutz, E., Hofmann, A.W., 1992. Potassium, rubidium, and cesium in the Earth and Moon and the evolution of the mantle of the Earth. Geochimica et Cosmochimica Acta 56, 1001–1012. https://doi.org/10.1016/0016-7037(92)90043-I.

Meschede, M., 1986. A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram*. Chemistry Geology, 56*, 207–218.

Miyashiro, A., 1974. Volcanic Rock Series in Island Arcs and Active Continental Margins. *American Journal of Science, 274*, 321-355.

Moore, J.N, Allis, R.G., Nemčok, M., Powell, T.S., Bruton, C.J., Wannamaker, P.E., Raharjo, I.B. and Norman, D.I., 2009, The evolution of volcano-hosted geothermal systems based on deep wells from Karaha - Telaga Bodas, Indonesia: American Journal of Science, v. 308, p. 1-48. Published, 2008.

Mullen, E.D., 1983. MnO/TiO2/P2O5: A Minor Element Discriminant for Basaltic Rocks of Oceanic Environments and Its Implications for Petrogenesis. Earth and Planetary Science Letters, 62, 53-62.

Neumann van Padang, M., 1951. Indonesia. Catalogue of the active volcanoes of the World. *Associate International Volcanology*, Napoli.

Pearce, J.A., Peate, D.W., 1995. Tectonic implications of the composition of volcanic arc magmas. Annual Review of Earth and Planetary Sciences 23, 251–285. http://doi.org/ 10.1146/annurev.ea.23.050195.001343.

Peccerillo, A., & Taylor, S.R., 1976. Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, N.E. Turkey. *Contrib. Mineral. Petrol, 58*, 63--81.

Siebert, L., Simkin, T., & Kimberly, P., 2010. Volcanoes of the world (Third Edi). *Berkeley, CA, USA: Univ of California Press*.

Silitonga, P.H., 1973. Peta Geologi Lembar Garut, Jawa, skala 1:100.000. *Direktorat Geologi,* Bandung.

Sun, S.S., & McDonough, W.F., 1989. Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In Magmatism in the Ocean Basins (Saunders, A.D. and Norry, M.J. Eds.). *Geological Society, London, Special Publications, 42,* 313-345, Geological Society, London.

Tatsumi, Y., & Eggins, S., 1995. Subduction Zone Magmatism. *Blackwell Science,* Oxford.

Williams, H., Turner, F. J., and Gilbert, C., 1954. *Petrography An Introduction to the Study of Rocks in Thin Section*, University of California, 406 p.