Petrology and Geochemistry of Volcanic Rocks around Kamojang Geohermal Field, West Java, Indonesia

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Petrology and Geochemistry of Volcanic Rocks around Kamojang Geohermal Field, West Java, Indonesia

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Abstract

Kamojang geothermal field is located in the Quartenary volcanic caldera system aged 0.45 to 1.2 Ma. Around the geothermal field, there are several volcanoes (composite cones) which includes: Mt. Sanggar, Mt. Ciharus, Mt. Jawa, Mt. Pasir Jawa and Mt. Cakra. These volcanoes contributes greatly to presence Kamojang geothermal system, which is dominated steam with high temperatures approximately 250°C. This field has a potential 260 MWe with 140 MWe installed capacity. Thus, more detailed study is need to find out the characteristics of volcanic complex. This study focused on petrology and geochemistry of volcanic rocks in Kamojang geothermal field.

The results of the petrography indicate that the overall of volcanic rocks in the study area have strongly porphyritic texture. Phenocryst abundant nearby 79-89%**,** which is composed of plagioclase (65-78%), pyroxene (5-14%) and opaque minerals (around 3-5%). The presence of pyroxene and opaque minerals indicates that the volcanic rocks of the study area occured iron enrichment, then decreased aligned with the process of differentiation magma. Major elements are applied to many diagrams. Some of them identfy the rock type as tholeite but most of the plots are calc-alkaline. Trace elements show the similarities with calc-alikaline island arec type. Some ambigious points are remined, the assemblage of volcanic rocks Kamojang complex will be island arc calc-alkaline affinity. There are no big chenge of magma process between pre and post caldera activities by the ditailed analyses of petrology and chemistry.

1. Introduction

Kamojang volcanic complex is located in Garut, West Java Province about 60 miles southeast from Bandung. Volcanic complex has a size of 15 km length and 4.5 km width. The area is bounded by Mt. Rakutak to the west and Mt. Guntur in the east. Mountain range is composed by several volcanoes that lined the west towards the east, include: Mount Rakutak, Ciharus Lake, Pangkalan Lake, Mount Gandapura, Mount Guntur and Mount Masigit. Mount Rakutak aged older than Mount Guntur and both are still active. The development of these volcanoes can be observed through alignment of magmatic center, where the development of volcanic began from west to east. This area is steam dominated with high temperatures approximately 250°C and it produces potential of 260 MWe with 140 MWe installed capacity. This study focuses on petrology and geochemistry of volcanic rocks at the Kamojang geothermal field. By studying petrology and geochemistry of the volcanic rocks is expected to know more details about characteristics of volcanic rocks that produce geothermal energy.

2. Geology of Kamojang Geothermal Field

The research area is the western part Indonesia, and is influenced by tectonic activity of subduction between the continental Eurasian Plate and Indian Ocean-Australian Plate since the Eocene and still continues today. In Java, the plates subducted front/upright can not form lateral fault system in the long dimension such as Sumatera Fault. The alignment patterns of geological structure in Java can be divided into 3 (three) directions at Meratus pattern trending northeast-southwest, Sunda pattern trending north-south and Java patterns trending west-east (Pulunggono and Martodjojo, 1994).

In Java, the plate subduction resulted series of volcanic activity. It started at least since Eocene (Katili, 1975; Hamilton, 1979; Rangin et al, 1990) or from 40 to 19-18 Ma (Soeria-Atmadja et al., 1994). Subsequent events occurred around 12 Ma or 11 Ma to 2 Ma (Smyth et al., 2008) and later covered by Quaternary volcanic deposits from Sunda arc group (Soeria-Atmadja et al., 1991; Soeria-Atmadja et al., 1994). Kamojang volcanic complex is part of Quaternary volcanoes series in West Java. According to Robert, et al. (1983) and Robert (1987), Kamojang compiled by volcanic deposits and are divided into the Pangkalan and Gandapura Formations in ascending order. The Pangkalan Formation aged 1.20 ± 0.02 Ma which occupied in western part, while the Gandapura Formation aged 0.452 ± 0.015 Ma (K-Ar method) occupied the eastern Kamojang. According to Kamah et al. (2003, 2005), generally geology of Kamojang geothermal area and surroundings are composed of volcanic deposits of pre and post caldera. The sequence of pre caldera formations are basalt (Mt. Rakutak), basalt (Dog-dog), pyroxene andesite (Mt. Cibereum), basaltic andesite pyroclastic (Mt.Sanggar), pyroxene andesite (Mt.Cibatuipis, Mt.Ciharus and Mt.Jawa), porphyrytic andesite (Mt.Katomas), basaltic andesite (Legokpulus and Mt.Putri), andesite (Mt.Pasir Jawa) and pyroxene andesite (Mt.Kancing) in ascending order. The post caldera formation sequence from old to young are Basaltic Andesite (Mt.Batususun and Mt.Gandapura), Andesite Lava (Mt.Gajah), Basaltic Andesite (Mt.Cakra and Mt.Guntur). The group of Post Caldera formations are unconformity overlaying the Pre Caldera formations.

3. Samples and Analitical Method

Petrographic observation and chemical analysis are done for eight volcanic rock samples from Mt.Sanggar (9), Mt.Ciharus (14), Mt.Jawa (23), Mt.Pasir Java (2 and 5) and Mt.Cakra (19, 27 and 35) (Figure 1). Among them, three samples (9, 2 and 5) are pre caldera and other five samples (14, 23, 19, 27 and 35) are post caldera deposits. All samples are representing the major eruption materials for studied volcanoes.

Petrographic observations are done by normal thin section microscopy. Major and trace elements are analyzed by the X-Ray Fluorences (XFR) method done in Geology Agency, Bandung, Indonesia.The acuracy is not high becasue powder pelet method can be appled.

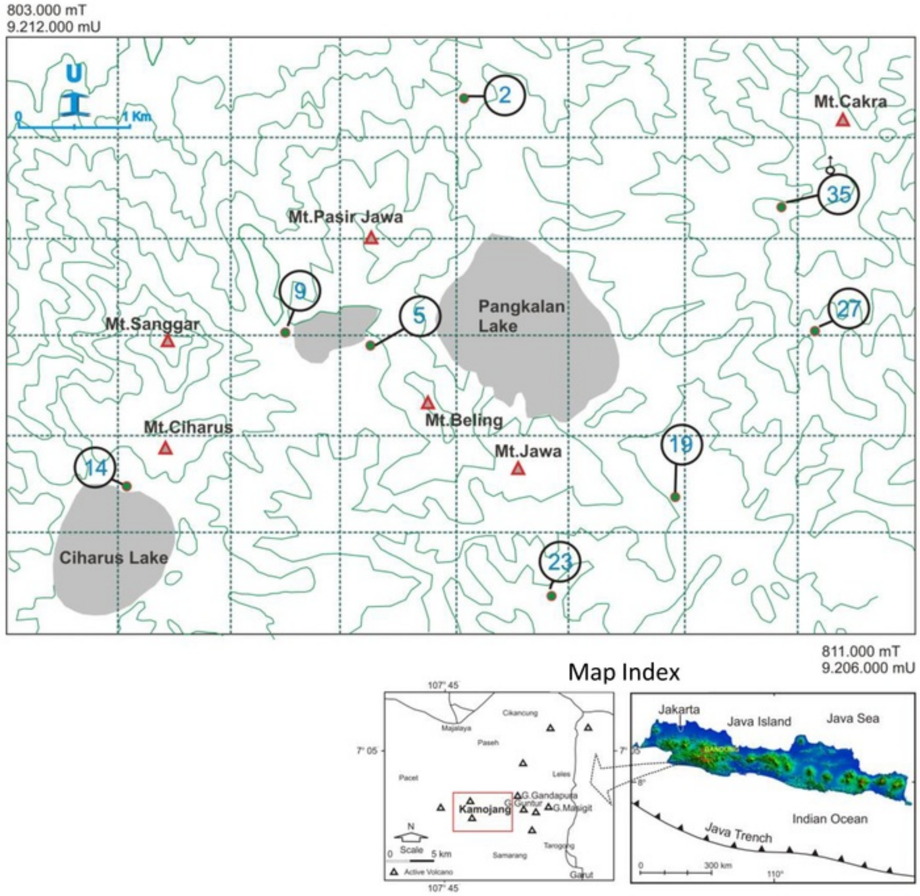

Figure 1. Locations of eight study samples at research area.

4. Research Results

4.1. Petrography

The summarized petrographic analyses are shown in Table 1. The volcanic rock types include basaltic andesite (samples 9 and 14) and pyroxene andesite (samples 2, 5, 19, 23, 27 and 35). Detailed explanations are described next sections.

Table 1. Petrographic analysis of volcanic rocks at the study area

No.	Code	Location	Rock type	Mineralogy		
				Pyroxene	Plagioclas	Opaque
1	14	Mt.Ciharus	Basaltic Andesite	θ	θ	O
2	9	Mt.Sanggar	Basaltic Andesite	θ	θ	O
3	5	Mt.Pasir Jawa	Pyroxene Andesite	θ	θ	O
4	27	Mt.Cakra	Pyroxene Andesite	θ	θ	O
5	35	Mt.Cakra	Pyroxene Andesite	θ	θ	O
6	2	Mt.Pasir Jawa	Pyroxene Andesite	θ	θ	O
7	23	Mt.Jawa	Pyroxene Andesite	θ	θ	O
8	19	Mt.Cakra	Pyroxene Andesite	θ	θ	O

O : phenocryst
— : groundmass

Basaltic Andesite

Basaltic andesites collected from Mt.Sanggar (9) and Mt.Ciharus (14) are gray color lavas and fine to medium grained (0.1 to 0.2 cm) porphyritic texture. Phenocryst composed of plagioclase, pyroxene and opaque minerals are embedded in groundmass volcanic glass. These rocks have partial alteration parts approximately 12-14%.

Microscopic observations of samples 9 and 14 are shown in Figure 2. These basaltic andesites are characterized by hypocrystaline, porphyritic, intergranular and intersertal texture. Phenocryst approximately 79-88% sized 0.2 to 1.2 mm and composed by plagioclase, pyroxene and opaque minerals. Groundmass (14-21%) generally composed of fine crystals consisting microlite plagioclase, pyroxene and opaque minerals. Some alteration minerals such as chlorite, clay and iron oxide seems to replace phenocryst on and the edge of the crystal, as well as replace some groundmass. Iron oxide veins are shown in the sample 14.

Plagioclase looks colorless, generally present as phenocryst and groundmass approximately 65-71%, and the type was Labradorite (An_{53}-An_{58}). Phenocryst is sized 0.2 to 0.7 mm and shows subhedral-anhedral lamera prismatic shape. Twinning was encountered albite and combination of carlsbad-albite. Some plagioclases show zoning and some phenocrystic plagioclases altered to patches of secondary minerals such as chlorite and other clay minerals.

Pyroxene (clinopyroxene) presents approximately 10%, as phenocryst and groundmass, prismatic shape (subhedral-anhderal) with size of 0.2 to 0.4 mm. Some pyroxene has been altered, especially on the edge becomes opaque minerals and chlorite. Some phenocrysts show corrosion of groundmass and opaque mineral.

Opaque minerals present around 4-5%, and scattered in pyroxene and groundmass. In sample 14, opaque minerals (iron oxides) present filling vein that cut some phenocryst and groundmass.

Volcanic glass presents 12-21% as finely groundmass along with microlite plagioclase and opaque minerals showing intergranular and intersertal texture.

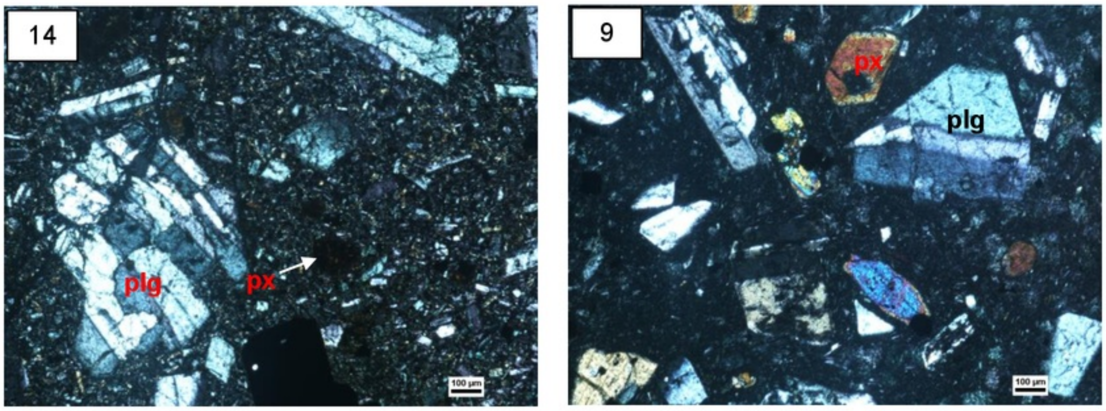

Figure 2. Petrography of basaltic andesite composed of plagioclase and pyroxene
(plg: plagioclase, px: pyroxene)

Pyroxene andesite

Pyroxene andesite lavas are collected from Mt.Jawa (23), Mt.Pasir Java (2 and 5) and Mt.Cakra (19, 27 and 35). These pyroxene andesite lavas are generally altered approximately 8-21%. In megascopis is gray color, fine to medium grain (0.1 to 0.2 cm) size with porphyritic texture. Phenocryst composed of plagioclase, pyroxene and opaque minerals are embedded in the groundmass of volcanic glass. In samples 2, 5, 19, 23, 27 and 35 show that rocks had alterated approximately 8-21%. Chlorite, clay, quartz and iron oxides minerals are present as alteration minerals that alter some plagioclase, pyroxene and groundmass.

Microscopic observations of the above five samples are shown in Figure 3. Some pyroxene andesites occourred as scoria, and generally show hypocrystaline porphyritic and intergranular texture. Phenocrysts (85-89%) sized 0.2 to 1.2 mm are consist of plagioclase, pyroxene and opaque minerals, and are embedded in the groundmass of volcanic glass (11-19%). Some opaque minerals inclusive plagioclase and pyroxene. Chlorite, other clay and opaque (iron oxide) minerals are occurred as alteration products at some phenocryst edges and parts of the groundmass. Contents of alteration minerals are approximately 8-21%. Veins are filled by chlorite, iron oxides and quartz in some thin sections of samples 5, 19 and 35.

Plagioclases (approximately 66-73%) appear as colorless, subhedral-anhedral and prismatic shape with sized from 0.2 to 1.2 mm, and present as phenocrysts and microlites in groundmass. Type of plagioclase is andesine (An_{45}-An_{49}). Phenocryst plagioclases are generally twins albite, carlsbad-albite and some crystals show zoning pattern. Chlorite and other clay minerals are appeared to replace some edges of plagioclases and crystal fragments.

Pyroxene (clinopyroxene) contents is about 12-14%, and is occurred as phenocryst and groundmass of subhedral -anhderal prismatic shape with size 0.2-0.4 mm. Some pyroxene edges alterd into of opaque minerals and chlorite. Some phenocrysts show corrosion by groundmass and opaque mineral inclusion.

Opaque minerals present around 3-5%, which sometimes occurred in groundmass and partly as pyroxene inclusion. In samples 5 and 19, opaque minerals (iron oxides) present filling veins cut some phenocryst and groundmass.

Volcanic glass (11-19%) present as finely groundmass with microlite plagioclase and opaque minerals showing intergranular texture.

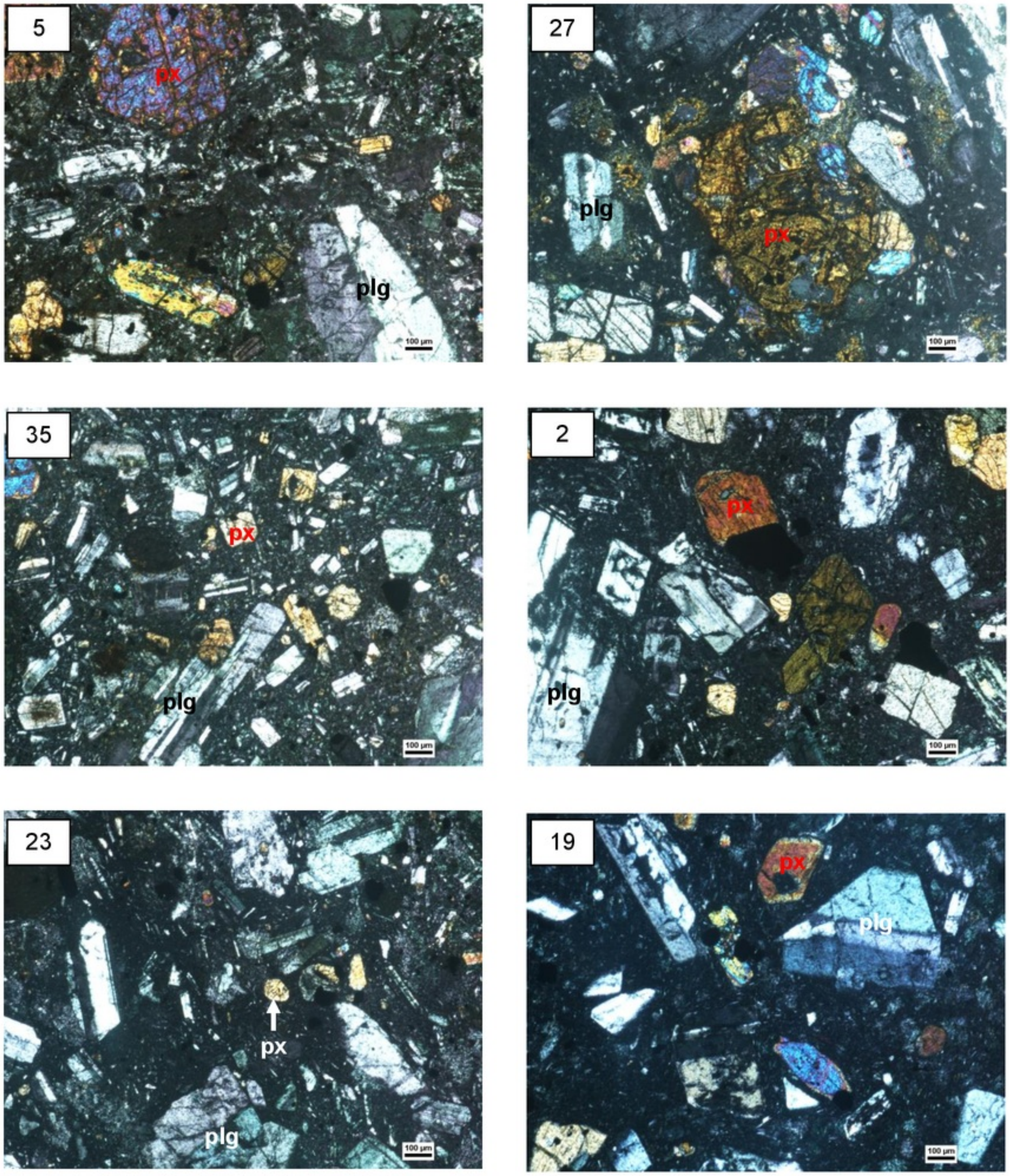

Figure 3. Petrography of pyroxene andesite composed by plagioclase and pyroxene
(plg: plagioclase, px: pyroxene)

Characterisics of volcanic rocks inferred from petrograpy

The volcanic rocks in the study area have strongly porphyritic texture. Ewart (1982) and Wilson (1989) proposed the idea that the strong porphyritic texture is island arc origin. Approximately 79-89% of abundant phenocryst composed of plagioclase (65-73%), pyroxene (10-14%) and opaque minerals (around 3-5%). The contents of pyroxene in pyroxene andesite is higher than basaltic andesite, and plagioclase is more acidic. The presence of pyroxene and opaque minerals indicates that the volcanic rocks of the study area occurred iron enrichment, then decreased following with the process of differentiation magma. Based on these characteristics, the volcanic rocks of study area are calc-alkaline composition (Hughes, 1982).

4.2. Geochemistry

The naming of volcanic rocks used in this study are following the classification Lebas (1986).

Geochemical analyses of eight volcanic rock samples are presented in Table 2. All of the rock samples analyzed showed content SiO_2: 54.42-61.46%, Al_2O_3: 16.06-18.50% and CaO: 4.42-7.97%. The content of K_2O and Na_2O consecutive varies between 0.77-1.87% and from 2.62-3.46%, and MgO content ranges from 1.24-2.57%. While concentration Fe_2O_3 and FeO respectively varies between 1.07-1.42% and 5.98-7.97%. The element oxides showed low concentrations, which: TiO_2: 0.61-0.92%, P_2O_5: 0.17-26% and MnO: 0.09- 0.17%. Value of lost of ignition (LOI) ranges of 1.11-4.02%, which indicates the rock has been weakly altered.

All data are plotted on the diagram proposed by Lebas (1986) which identidied the rock type by SiO_2 and K_2O+Na_2O contents. Two samples (9 and 14) are the range of basaltic andesite and six samples (2, 5, 19, 23, 27 and 35) are pyroxene andesite (Figure 4).

Table 2. Major and trace elements contents of volcanic rocks in studied area

Major	Basaltic Andesite		Piroxene Andesite					
Element	Mt.Ciharus	Mt.Sanggar	Mt.Pasir Jawa	Mt.Cakra	Mt.Cakra	Mt.Pasir Jawa	Mt.Jawa	Mt.Cakra
(% w)	14	9	5	27	35	2	23	19
SiO_2	54.42	54.45	58.77	59.89	60.14	60.98	61.38	61.46
TiO_2	0.92	0.91	0.63	0.67	0.73	0.63	0.61	0.65
Al_2O_3	18.50	18.50	16.66	16.18	16.06	17.75	16.63	16.91
Fe_2O_3	1.42	1.41	1.32	1.17	1.24	1.07	1.15	1.07
FeO	7.97	7.90	7.41	6.56	6.93	6.01	6.46	5.98
MnO	0.17	0.16	0.12	0.12	0.11	0.11	0.11	0.09
MgO	2.12	2.12	1.76	2.38	2.57	1.51	1.54	1.24
CaO	7.97	7.87	5.00	5.87	5.81	4.42	5.72	5.47
Na_2O	3.46	3.44	2.62	2.88	2.71	2.66	3.08	2.97
K_2O	0.77	0.77	1.45	1.61	1.73	1.77	1.55	1.87
P_2O_5	0.26	0.26	0.18	0.18	0.16	0.18	0.18	0.17
LOI	1.26	1.21	4.02	2.25	1.21	2.49	1.11	1.93
Norm (% w)								
Q	5.96	6.32	19.12	16.13	23.13	22.81	17.98	19.01
or	4.67	4.67	8.92	9.75	10.40	10.81	9.34	11.29
ab	29.81	29.64	23.19	25.05	23.28	23.11	26.41	25.65
an	33.45	33.65	24.66	27.16	11.96	21.38	27.49	26.62
C	-	-	2.21	-	5.57	3.99	-	0.49
di	4.47	3.92	-	1.34	-	-	0.18	-
hy	19.23	19.40	20.22	18.84	20.57	16.22	16.99	15.28
il	1.79	1.77	1.25	1.31	1.41	1.23	1.18	1.25
ap	0.63	0.63	0.44	0.42	0.38	0.44	0.42	0.39
hl	0.03	0.03	-	-	0.02	0.02	0.02	0.02
fl	-	-	-	-	4.59	-	-	-
Trace element (ppm)								
Sc	27	-	-	-	-	-	-	-
V	182	182	133	139	165	123	146	127
Cr	23	38	36	27	76	29	33	35
Ni	-	-	-	-	-	46	-	-
Cu	75	68	37	49	52	18	54	-
Zn	70	73	56	53	60	53	44	54
Rb	-	-	-	-	29	31	26	-
Sr	276	261	170	228	189	172	235	211
Y	25	21	21	27	39	28	28	65
Zr	97	100	119	163	155	187	153	186
Ba	-	-	-	-	-	194	-	219
Pb	-	32	-	33	-	-	50	-
Se	-	20	28	-	-	-	-	-
As	-	128	61	129		98	129	-
Co	60	53	69	50	72	51	50	50
Cl	157	155	45	41	71	61	72	76
Ga	19	18	17	-	19	16	16	-
Bi	-	22	36	-	-	-	-	-
Tl	-	74	-	-	-	-	-	-
F	-	-	-	-	22,500	-	-	-

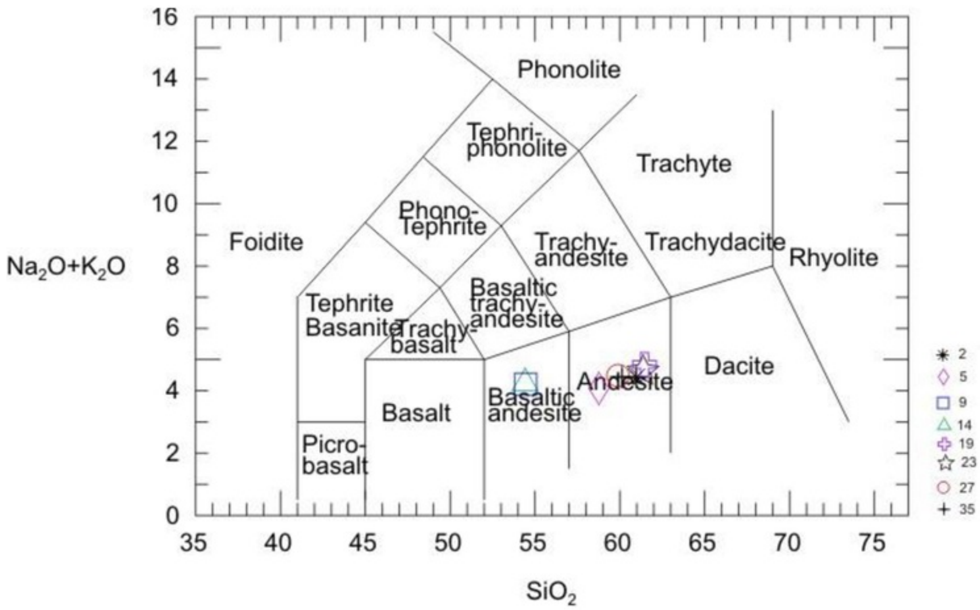

Figure 4. Plot of volcanic rocks of study area to the diagram proposed by Lebas (1986)

The plot of volcanic rock samples to the Peccerillo and Taylor diagram (1976) showed that basaltic andesite samples (9 and 14) are calc-alkaline low K, and pyroxene andesite samples (other six) are calc-alkaline medium K affinitis (Figure 5.).

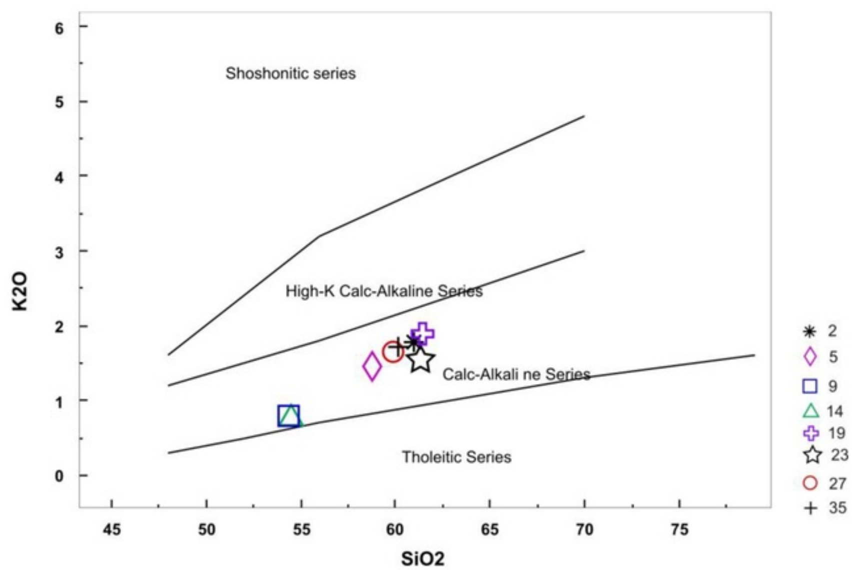

Figure 5. Plot of volcanic rocks in the study area to the diagrams propsed by Peccerillo and Taylor (1976)

Harker variation diagram

All major elements are plotted inHarker diagram (Figure 6). Plot between SiO_2 versus other element oxides could explain the development of magma differentiation processes. The results of these plots obtained three trend patterns of positive, negative and diffuse with increasing SiO_2 contents.

The positive pattern is variation of SiO_2 versus。 K_2O. It is explained by the formation of orthoclase (in norm) or volcanic glass during differentiation of magma. The negative trend is shown for the variation of SiO_2 versus Fe_2O_3, FeO, MnO, CaO, P_2O_5, and TiO_2. This can be explained by crystallization of pyroxene, opaque minerals (titano-magnetite/TiO_2) and apatite (P_2O_5). The variation diagram of SiO_2 versus Al_2O_3, MgO and Na_2O show spread patterns. It is explained that the differentiation of magma forming plagioclase minerals. Some possibilities for alteration effect can be considered but not so clear

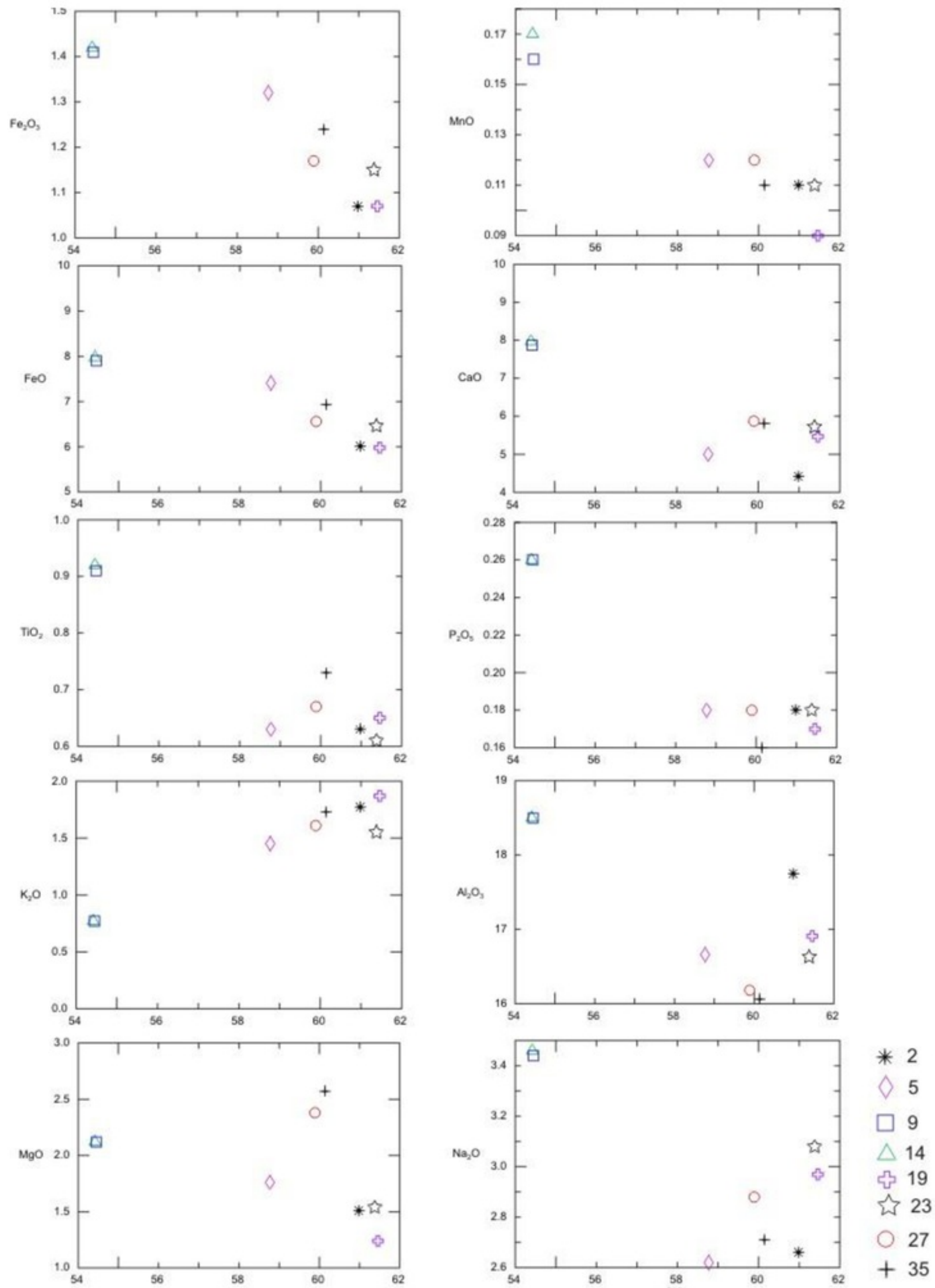

Figure 6 Variation diagrams major elements versus SiO_2 of volcanic rock at the research area

AFM diagram

AFM diagram is a triangular diagram of Irvin and Baragar (1971) with the variation of A ($Na_2O + K_2O$), F (Fe_2O_3+FeO) and M (MgO) to explain trending of magmatic affinities. Figure 7 is the plot of eight samples in this study. Assemblage volcanic rocks studied area showed trending iron enrichment group. The volcanic rocks studied area are plotted on both tholeitic and of calc-alkaline zones clasified by Miyashiro (1974). Iron enrichment was also supported by petrographic observations with the presence of opaque minerals (Titano-magnetite).

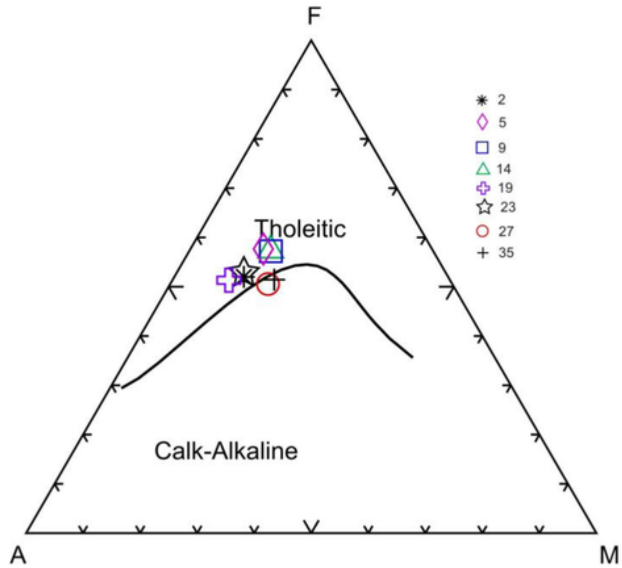

Figure 7. Data plot on the AFM diagram proposed by Irvin and Baragar (1971)

Normative mineralogy

The results chemical analysis of major elements can be used to determine the parameters of normative mineralogy (CIPW classification).

Normative mineral calculation results indicate that all samples contained quartz normative of 5.96-23.13%, which suggesting the silica saturated. Silica saturation is also demonstrated by the presence of hipersten normative (15.28-20.57%). The content of corundum (C norm) is about 0.49-5.57% in samples 2, 5, 19 and 35. Orthoclase normative present around 4.67-10.81% and the mineral is present in groundmass of volcanic glass.

Trace elements

The results of the analysis trace elements in volcanic rock samples indicate that the content of Rb (26-31 ppm), Sr (172-276 ppm), Ba (194-219 ppm), Cr (23-76 ppm), Ni (46 ppm), Y (21-65 ppm) and Zr (97-187 ppm). This trace element analysis has similarities with the results of the analysis of volcanic rocks calc-alkaline island arc as proposed by Luff (1982) which mentions that the content of trace elements in volcanic rocks calc-alkaline island arc are: Rb (29 ppm), Sr (137 ppm), Ba (243 ppm), Cr (28 ppm), Ni (3 ppm), Y (39 ppm) and Zr (126 ppm). It is difficult to discuss more because the data of this study is limitted.

Tectonic environment

Major elements are plotted in the tectonic discriminant diagram of Mullen (1983) to interpret the tectonic environment. Contents of MnO, TiO_2, P_2O_5 are used in this analysis. As Figure 8 shows, tectonic environment of volcanic rocks of study area are inferred island-arc calc-alkaline basalt (CAB) or island-arc tholeiite (IAT).

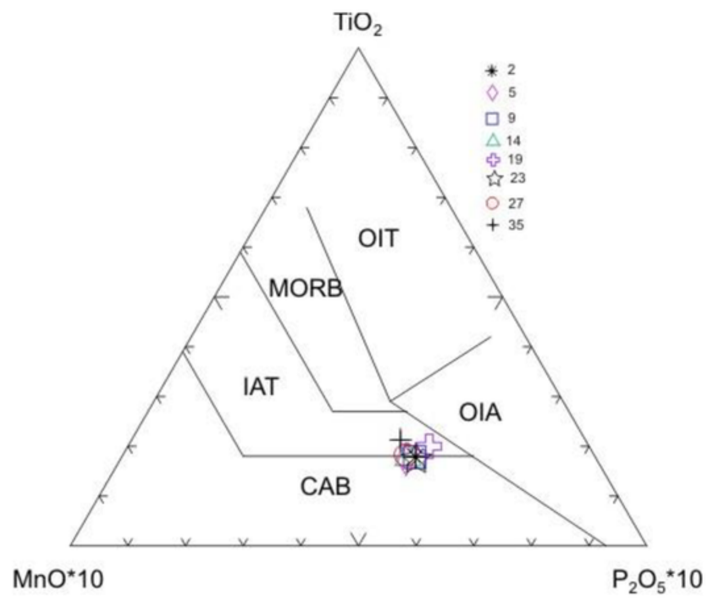

Figure 8. Plot of volcanic rocks of study area in discriminant diagrams MnO-TiO_2-P_2O_5 (Mullen, 1983) (MORB-mid-oceanic ridge basalt; OIT-oceanic island tholeiite or Seamount tholeiite; OIA-ocean island alkali basalt or alkali basalt Seamount; CAB-island-arc calc -alkaline basalt; IAT-island-arc tholeiite)

Conclusion

- The results of the petrography indicate that the overall of volcanic rocks in the study area have strongly porphyritic texture. Phenocryst abundant nearby 79-89% which is composed of plagioclase (65-78%), pyroxene (5-14%) and opaque minerals (around 3-5%). The presence of pyroxene and opaque minerals indicates that the volcanic rocks of the study area occured iron enrichment, then decreased aligned with the process of differentiation magma.
- Major elements are applied to many diagrams. Some of them identfy the rock type as tholeite but most of the plots are calc-alkaline.
- Trace elements show the similarities with calc-alikaline island arc type.
- Some ambigious points are remained, the assemblage of volcanic rocks Kamojang complex will be island arc calc-alkaline affinity.
- There are no big change of magma process between pre and post caldera activities by the detailed analyses of petrology and chemistry.

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