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"INCREASING ROLE OF EARTH SCIENCE AND TECHNOLOGY TO SUPPORTING ACCELERATION OF MINERAL AND ENERGY RESOURCES CONSERVATION"

Petrology and Geochemistry Volcanic Rocks of Volcanic Complex Kamojang Geothermal Field West Java Indonesia

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Abstract

Kamojang geothermal field is located in the Quartenary of volcanic caldera system aged 0.452 to 1.2 Ma. Around the geothermal field, there are several volcanoes (cinder cones) which includes: G.Sanggar, G.Ciharus, G.Jawa, G.Pasir Java and G.Cakra. This volcanic complex contributes greatly to presence Kamojang geothermal field, which is dominated steam whith high temperatures approximately 250°C. This field having potential 260 MWe with 140 MWe capacity. Thus needed to study to find out more detailed information about characteristics of volcanic complex. In this study focused on petrology and geochemistry of volcanic rocks in Kamojang geothermal field.

Basing on the above ideas, this study using petrographic observations and geochemical analyzes of volcanic rocks. This study is expected to contribute to knowledge about characteristics of the Kamojang geothermal field in particular and geothermal exploration in general

The results of petrology and geochemistry analysis of the volcanic rock showed that the characteristics of volcanic rocks consists of basaltic andesite and pyroxene andesite. In petrographic characteristics have content of abundant plagioclase, is accompanied by pyroxene and opaque minerals. While chemically has SiO_2 content: 54.42-61.46%, Al_2O_3: 16.06-18,50% and CaO: 4.42-7.97%. K_2O and Na_2O respectively varies between 0.77-.87% and 2.62-3.46%, and MgO ranges from 1.24-.57%. Concentration of Fe_2O_3 and FeO consecutive varies between 1.07-1.42% and 5.98-7.97%. The element oxides showed low concentrations, ie: TiO_2: 0.61-0.92%, P_2O_5: 0.17-0.26% and MnO: 0.09-0.17%. The content of trace elements 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). Based on the results of petrographic and geochemical analysis shows that the group of volcanic rock Kamojang volcanic complex included in calc-alkaline affinity that located at island arc.*

1. Introduction

Kamojang volcanic complex located in Garut, West Java Province, ie about 60 miles from Bandung to southeast. Volcanic complex is geographically located in series a large volcanic length 15 km and width 4.5 km. The area is bounded by G. Rakutak to the west and G.Guntur in the east. Mountain range is composed by several volcanoes that lined the west towards the east, include: G.Rakutak, Ciharus Lake, Pangkalan Lake, G.Gandapura, G.Guntur and G.Masigit. G.Rakutak aged older than G.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 install 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. Methodology Analysis

In conducting this study using petrographic observations and geochemical analyzes. Geochemical analysis of volcanic rocks included analysis of major and trace elements. This study is expected to contribute to knowledge about the characteristics of the Kamojang geothermal field in particular and geothermal exploration in general.

3. Geology of Kamojang Geothermal Field

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

In Java, the results of plate subduction resulted series of volcanoes and volcanic activity, it takes place at least since Eocene (Katili, 1975; Hamilton, 1979; Rangin et al, 1990), ie from 40 to 19-18 Ma (Soeria-Atmadja et al., 1994). Subsequent events occurred among 12 Ma or 11 Ma to 2 Ma (Smyth et al., 2008) and later covered by Quaternary volcanic deposits from Sunda arc (Soeria-Atmadja et al., 1991; Soeria-Atmadja et al., 1994). Kamojang volcanic complex is part of series Quaternary volcanoes in West Java, and according to Robert, et al. (1983) and Robert (1987) that geologically Kamojang compiled by volcanic deposits consist of two formations (from old to young) ie Pangkalan Formation and Gandapura Formation. Pangkalan Formation aged 1.2 ± 0.02 Ma which occupied in western part, while Gandapura Formation aged 0.452 ± 0.05 Ma (K-Ar method) occupied the eastern Kamojang. According Kamah et al. (2003, 2005) in generally geology of Kamojang geothermal area and surrounding composed by volcanic deposits of Pre and Post Caldera. The sequence of Pre Caldera formation volcanic deposits from old to the youngest are Basalt G.Rakutak, Basalt Dog-dog, Pyroxene Andesite G.Cibereum, Pyroclastic G.Sanggar, Pyroxene Andesite G.Cibatuipis, Andesite Porphyry G.Katomas, Basaltic Andesite Legokpulus and G.Putri, Andesite Lava G.Pasir Java and Pyroxene Andesite G.Kancing. Post caldera formation sequence from old to young are Basaltic Andesite G.Batususun and G.Gandapura, Andesite Lava G.Gajah, Basaltic Andesite G.Cakra-Masigit and G.Guntur. The groups of Post Caldera formations are unconformity overlaying the Pre Caldera formation.

4. Research Results

4.1. Petrographic

Petrographic analysis done on eight samples of volcanic rocks that represent some volcanoes at the research area, which: G.Sanggar (9), G.Ciharus (14), G.Jawa (23), G.Pasir Java (2 and 5) and G.Cakra (19, 27 and 35). The naming of volcanic rocks used in this study are following the classification Lebas (1986). Basaltic rocks are rocks which contain SiO_2 <52%, basaltic andesitic contain 52-57% SiO_2. Andesitic rocks have content SiO_2 57-63% and dasitics contain 63-68% SiO_2, whereas riolitic rocks SiO_2 content > 68% (Figure 4.3.). Petrographic analysis of samples volcanic rocks in study area (Table 4.1) indicate that the volcanic rock types include: basaltic andesite and pyroxene andesite. Basaltic andesite rocks are owned by 9 and 14, while pyroxene andesite rocks (ie: samples 2, 5, 19, 23, 27 and 35).

Table 4.1. Petrographic analysis of volcanic rocks at study area

No.	Code	Location	Name of Rocks	Mineralogy		
				Pyroxene	Plagioclas	Opaque
1	14	G.Ciharus	Basaltic Andesite	ϴ	ϴ	O
2	9	G.Sanggar	Basaltic Andesite	ϴ	ϴ	O
3	5	G.Pasir Jawa	Pyroxene Andesite	ϴ	ϴ	O
4	27	G.Cakra	Pyroxene Andesite	ϴ	ϴ	O
5	35	G.Cakra	Pyroxene Andesite	ϴ	ϴ	O
6	2	G.Pasir Jawa	Pyroxene Andesite	ϴ	ϴ	O
7	23	G.Jawa	Pyroxene Andesite	ϴ	ϴ	O
8	19	G.Cakra	Pyroxene Andesite	ϴ	ϴ	O

O : phenocryst

— : groundmass

Basaltic Andesite

Basaltic andesite volcanic rocks exposed at G.Sanggar (9) and G.Ciharus (14) are lavas, gray, fine to medium grained (0.1 to 0.2 cm) with porphyritic texture. Phenocryst composed of plagioclase, pyroxene and opaque minerals are embedded in groundmass volcanic glass. These rocks have experienced partial alteration approximately 8% and alteration minerals are chlorite, clays and iron oxides. In sample14 looks some iron oxide veins cut the rock.

Microscopically the basaltic andesite characterized by hypocrystaline, porphyritic, intergranular and intersertal texture. Phenocryst approximately 82-88% sized 0.2 to 1.2 mm and composed by plagioclase, pyroxene and opaque minerals. Groundmass (10-12%) 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. Some rocks are cut by iron oxide vein it as shown in the sample 14.

Plagioclase looks colorless, generally present as phenocryst and groundmass approximately 72-75%, as groundmass was fine crystal and the type was Labradorite (An_{53}-An_{58}). Phenocryst sized 0.2 to 0.7 mm or lameral shaped prismatic subhedral-anhedral. Twinning was encountered Albit and combination Carlsbad-Albit. Some plagioclase shows zoning composition and some individuals phenocryst plagioclase has been altered and show patches of secondary minerals such as chlorite and clay minerals.

Pyroxene (clinopyroxene) attends approximately 5-8%, as phenocryst and groundmass, prismatic shape (subhedral-anhderal) with size 0.2 to 0.4 mm. Some pyroxene has been altered, especially on the edge becomes opaque minerals and chlorite and some individual phenocryst shows corrosion by groundmass and inclusions by opaque mineral.

Opaque minerals are present around 5%, as an individual mineral, sometimes in groups and some inclusion pyroxene. In general, opaque minerals present with groundmass. In sample 14 appears opaque minerals (iron oxides) present filling vein that cut some phenocryst and groundmass in thin section.

Volcanic glass 10-12% presents as finely groundmass along with microlite plagioclase and opaque minerals showing intergranular and intersertal texture.

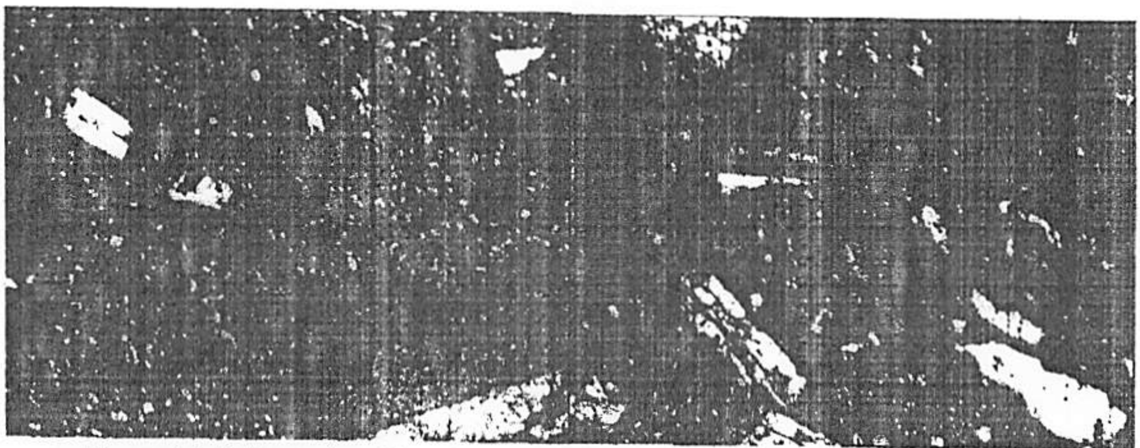

Figure 4.1. Petrography of basaltic andesite composed by plagioclase and pyroxene (plg: plagioclase, px: pyroxene)

Pyroxene andesite

Pyroxene andesite lava and found as exposed in G.Jawa (23), G.Pasir Java (2 and 5) and G.Cakra (samples: 19, 27 and 35). Pyroxene andesite lava is generally slightly altered approximately 1-12%. In megascopis is gray colour, fine to medium grain (0.1 to 0.2 cm) 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 1-12%. Chlorite, clay, quartz and iron oxides minerals are present as alteration minerals that alter some plagioclase, pyroxene and groundmass.

Microscopically, part of pyroxene andesite shows scoria structure and generally hypocrystaline porphyritic and intergranular texture. Phenocryst (82-89%) sized 0.2 to 1.2 mm consists of plagioclase, pyroxene and opaque minerals are embedded in the groundmass of volcanic glass (8-15%). Some opaque minerals inclusive plagioclase and pyroxene. Chlorite, clay minerals and opaque (iron oxide) altered some phenocryst on and the edge of the crystal and some parts of the groundmass. Abundant of alteration minerals are approximately 1-12%. Veins are filled by chlorite, iron oxides and quartz does present in some thin section, which are samples: 5, 19 and 35.

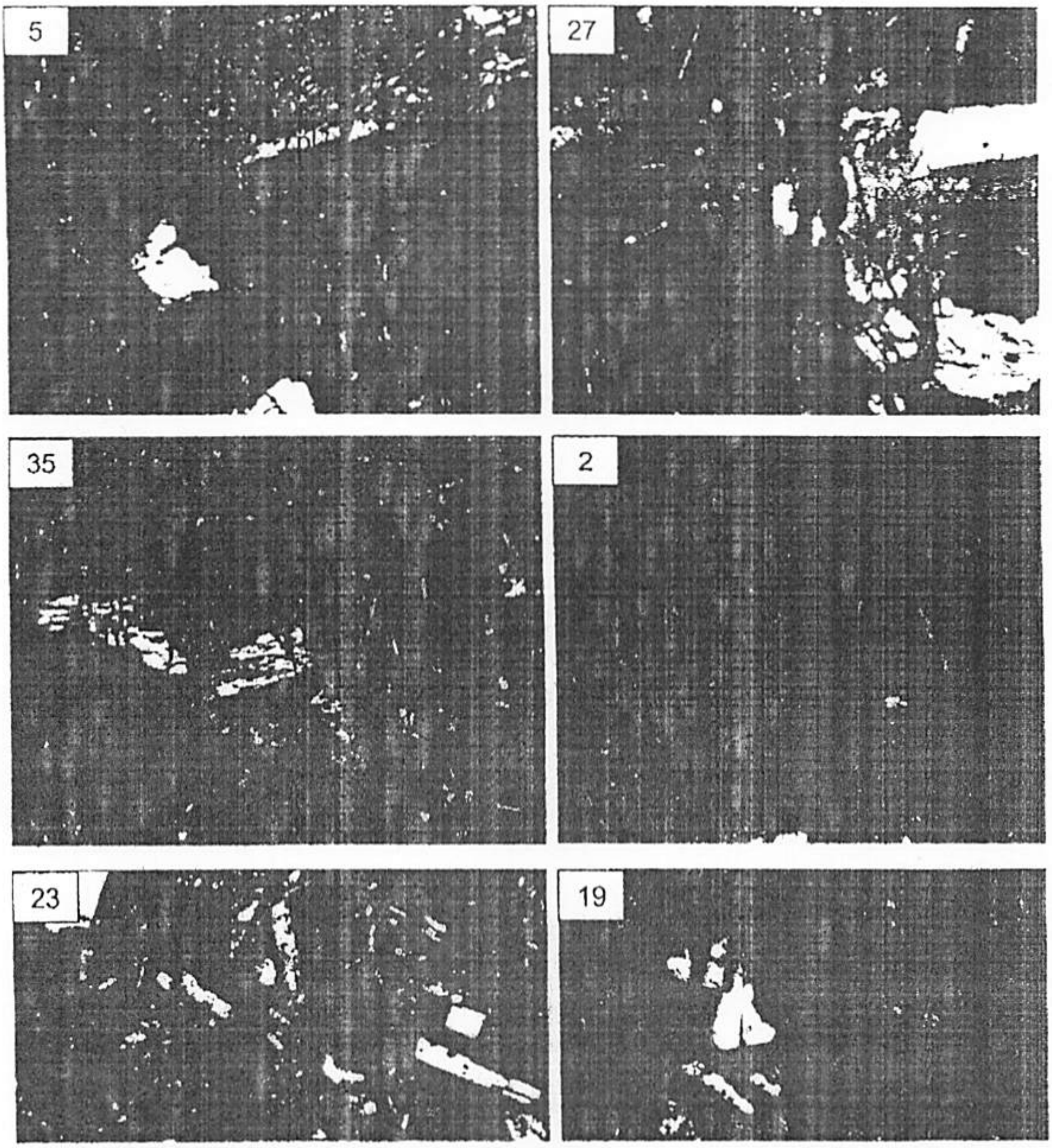

Figure 4.2. Petrographic of pyroxene andesite composed by plagioclase and pyroxene (plg: plagioclase, px: pyroxene)

Based on the results of petrography analysis indicate that generally volcanic rocks in the study area have strongly porphyritic texture. These characteristics by Ewart (1982) and Wilson (1989) included in the characteristics of volcanic rocks island arc. Abundant phenocryst approximately 82-89%, which composed of plagioclase (65-75%), pyroxene (5-14%) and opaque minerals around 3-5%. Plagioclase tended more acidic, while the amount of pyroxene in pyroxene andesite more than basaltic andesite. 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, so the petrografis of volcanic rocks the study area is calc-alkaline composition (Hughes, 1982).

Pyroxene (clinopiroxene) was present about 12-14%, as phenocryst and groundmass, subhedral -anhderal prismatic with size 0.2-0.4 mm Some pyroxene had alteration, especially on the edge of crystal altered becomes opaque minerals and chlorite. Some individual phenocryst shows corrosion by groundmass and opaque mineral inclusion.

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

Volcanic glass 8-15% present as finely groundmass with microlite plagioclase and opaque minerals showing intergranular texture.

Plagioclase attend approximately 65-72% appear colorless, subhedral-anhedral, prismatic, sized from 0.2 to 1.2 mm was present as phenocryst and microlite in groundmass. Type of plagioclase was Andesine (An_{45}-An_{49}). Phenocryst plagioclase generally showed twins Albit, Carlsbad-Albit and some individuals show zoning composition. Chlorite and clay minerals was present to replace some of the edges plagioclase and crystal fragments.

4.2. Geochemistry

Geochemical analysis 8 volcanic rock samples are presented in Table 4.2. 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) ranged of 1.11-4.02%, it indicates that the rock has been altered due to hydrothermal alteration processes.

Classification of volcanic rocks of the study area based on the results of the main plot of the chemical elements in the rock classification diagram according to Lebas (1986) include: basaltic andesite and pyroxene andesite. Basaltic andesite rock samples represented by 9 and 14 with the characteristics of content SiO_2: 54.42-54.45%, while pyroxene andesite rocks (which: samples 2, 5, 19, 23, 27 and 35) have SiO_2 contents of 58.77-61.46% (see Figure 4.3.).

Table 4.2. The results of geochemical analysis of volcanic rocks studied area

Major Element (% w)	Basaltic Andesite		Pyroxene Andesite					
	G.Ciharus	G.Sanggar	G.Pasir Jawa	G.Cakra	G.Cakra	G.Pasir Jawa	G.Jawa	G.Cakra
	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	0.25	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	[illegible]	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	167	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	.	-	.

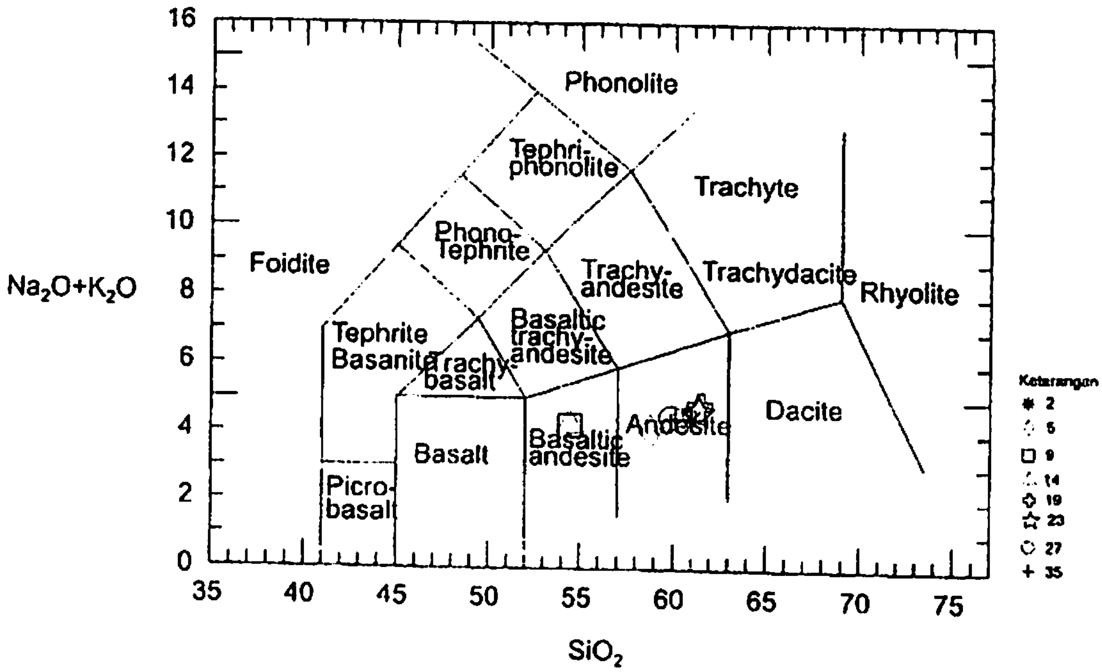

Figure 4.3. Classification of volcanic rocks of the study area according to Lebas (1986)

The results of plot of volcanic rock samples in the Peccerillo and Taylor diagram (1976) showed that all the rocks of basaltic andesite and andesite pyroxene classified into calc-alkaline medium K affinity, the concentration of the elements that characterize the affinity was SiO_2: 54.42-61.46% and K_2O varies between 0.77-1.87% (Figure 4.4.).

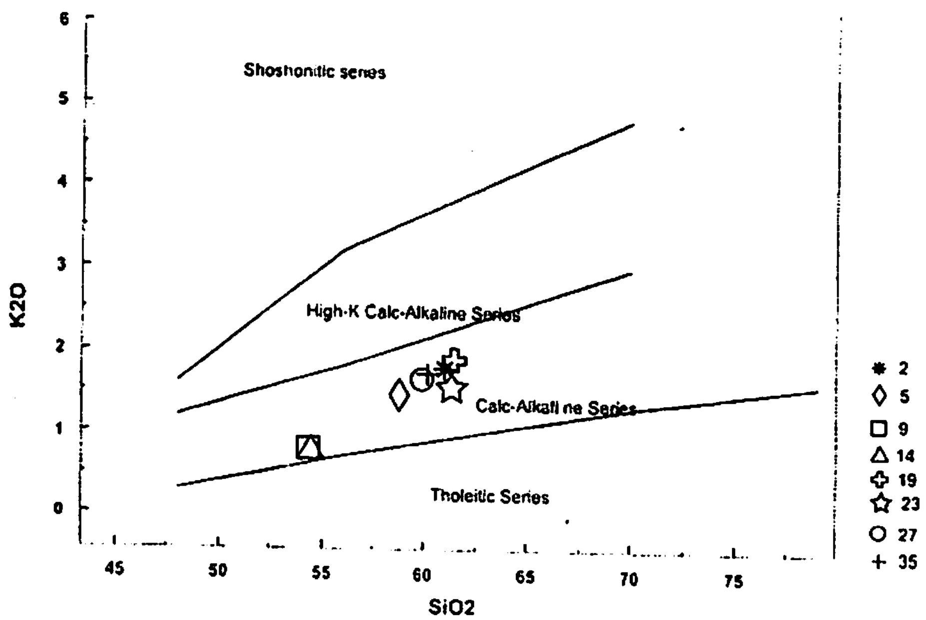

Figure 4.4. Affinity diagrams of volcanic rocks in the study area (Peccerillo and Taylor, 1976)

Harker variation diagram

Diagram variety of rock samples analyzed are presented in Figure 4.5., the abscissa axis is SiO_2, while ordinate axis an element oxides. Plot between element oxides could explain the development of magma differentiation processes and the results of these plots obtained 3 (three) trend patterns, that is: positive, negative and diffuse pattern with increasing SiO_2 element.

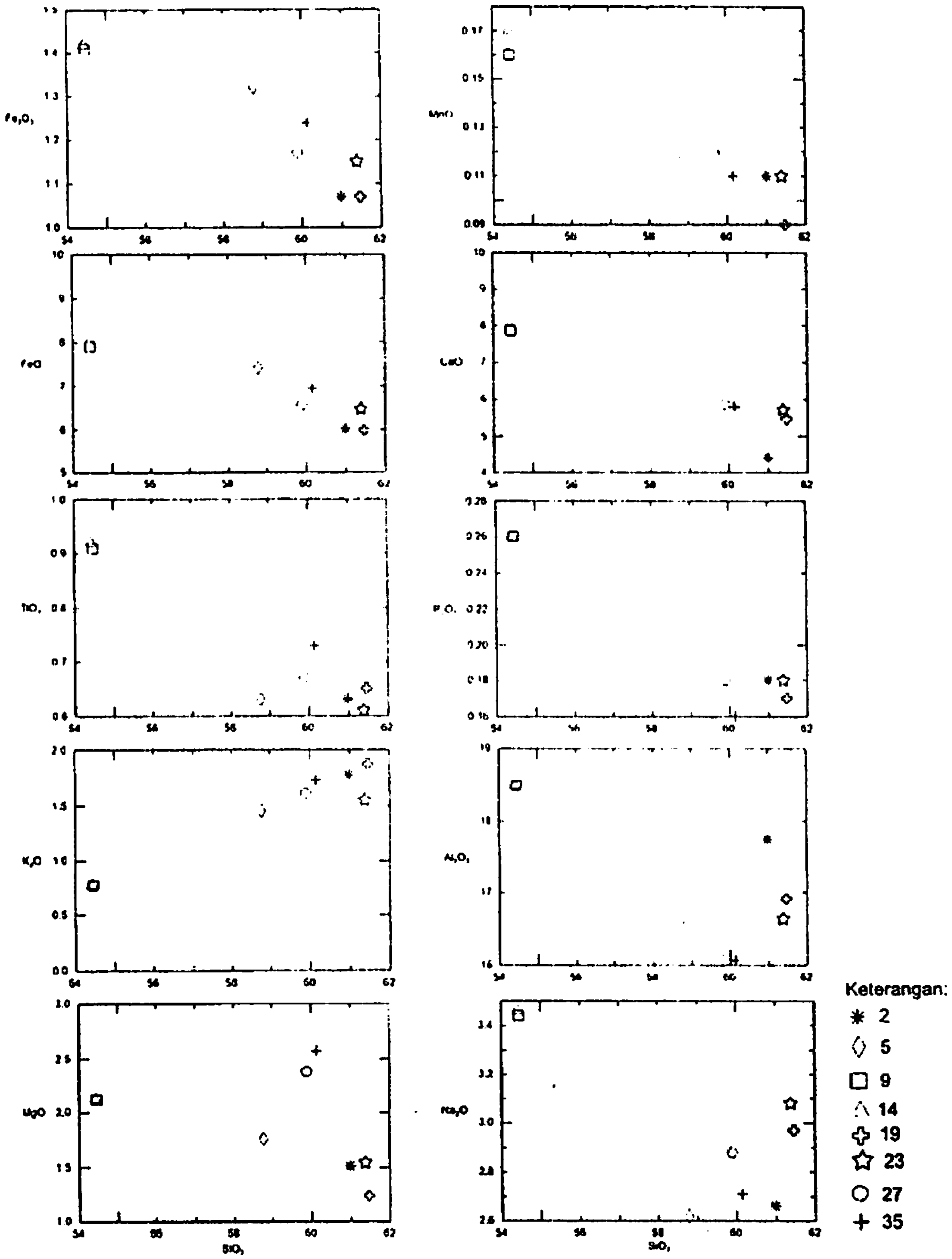

Figure 4.5. Variation diagrams major element to SiO_2 of volcanic rock at the research area

The diagram variation of oxide element that shows positive pattern was variation of K_2O versus SiO_2. It is explains that during differentiation magma occured orthoclase (in norm) or as volcanic glass. The negative trend was shown by the variation conten SiO_2 to Fe_2O_3*, FeO, MnO, CaO, P_2O_5, and TiO_2. With increasing SiO_2, then the process differentiation magma will occurred crystallization pyroxene, opaque minerals (titano-magnetite/TiO_2) and apatite (P_2O_5). On the variation diagram of SiO_2 to Al_2O_3, MgO and Na_2O show spread patterns, thus it is explains that during differentiation magma formed plagioclase mineral. However, some volcanic rock samples undergo hydrothermal alteration, so the spread pattern is caused by the presence of alteration minerals such as clays, chlorite and iron oxide

AFM diagram

This diagram is a triangular diagram of Irvin and Baragar (1971) with the variation of A (Na_2O + K_2O), F (FeO*) and M (MgO) to explain trending of magmatic affinities based on the elements mentioned above (Figure 4.6.). Assemblage volcanic rocks studied area showed trending iron enrichment (Fe) and then iron decreased. Such this pattern, according to Miyashiro (1974) showed that the volcanic rocks studied area was calc-alkaline affinity. Iron enrichment was also supported by petrographic observations with the presence of opaque minerals (Titano-magnetite).

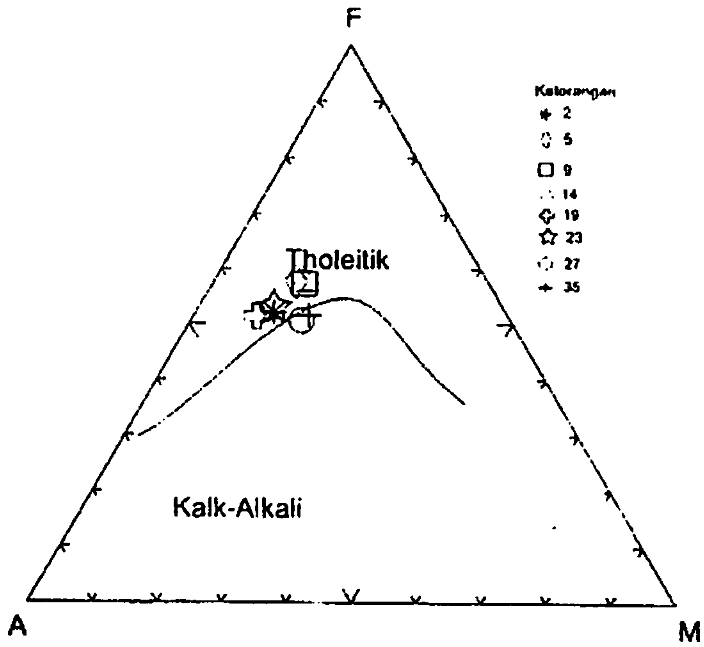

Figure 4.6. A triangular diagram (Na2O + K2O), F (FeO*) and M (MgO) by Irvin and Baragar (1971) for volcanic rocks affinity research area

Normative mineralogy

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

Normative mineral calculation results indicate that all samples contained quartz normative nearby 5.96-23.13%, suggesting the rocks are silica saturated. Silica saturation is also demonstrated by the presence of hipersten normative (15.28-20.57%). The content of corundum (C norm) of about 0.49-5.57% in samples 2, 5, 19 and 35 indicate that the rocks containing high alumina, or it can be interpreted that the rock altered hydrothermally, resulting in increasing alumina. Orthoclase normative present around 4.67-10.81% and the mineral is present in groundmass of volcanic glass.

Tectonic environment

To interpret the tectonic environment by doing plot major element in the tectonic discriminant diagram of Mullen (1983). In this analysis used MnO, TiO_2, P_2O_5 elements. The results of the discriminant plot are presented in triangular diagram MnO-TiO_2-P_2O_5 (Figure 4.7.). By Mullen (1983) indicate that tectonic environment of volcanic rocks within the study area including island-arc calc-alkaline basalt (CAB).

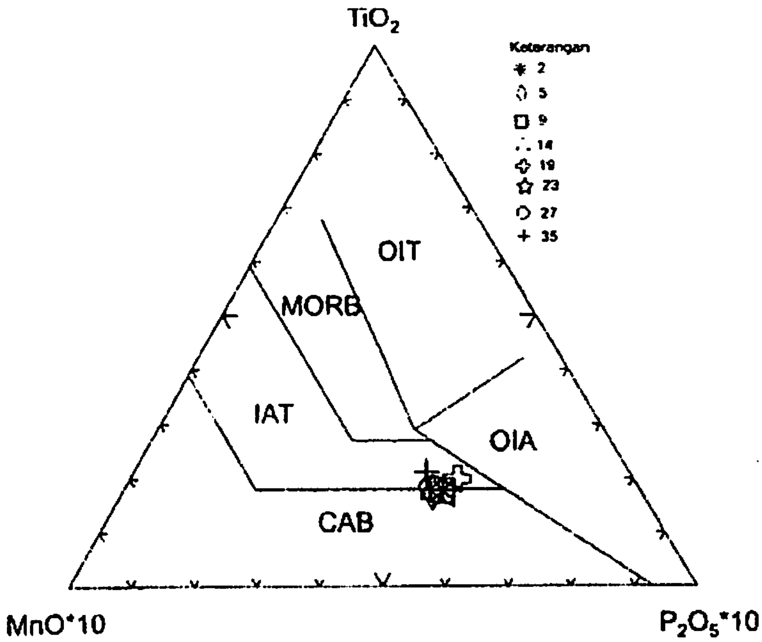

Figure 4.7. Plot of volcanic rocks of study area in discriminant diagrams MnO-TiO2-P2O5 (Mullen, 1983) (MORB-mid-oceanic ridge basalt; OIT-oceanic island tholeiite or Seamount tholeiite; OIA-ocean island alkali basalt or alkali basalt Seamount; CAB-island-arc calc -alkaline basalt; IAT-island-arc tholeiite)

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).

Conclusion

- Based on the results of the analysis petrography indicate that the overall of volcanic rocks in the study area have strongly porphyritic texture. Phenocryst abundant nearby 82-89%, which is composed of plagioclase (65-75%), pyroxene (5-14%) and opaque minerals around 3-5%. Plagioclase tended more acidic, while amount of pyroxene in andesite pyroxene greater than basaltic andesite. The presence of minerals 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.
- Chemically have major chemical content of 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 2.62-3.46%, and MgO content ranges 1.24-2.57%. Concentration Fe_2O_3* and FeO respectively varies between 1.07 to 1.42% and 5.98-7.97%. The element oxides showed low concentrations, that is: TiO_2: 0.61-0.92%, $P2O_5$: 0.17-0.26% and MnO: 0.09-0.17%. The content of trace elements 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).

- Based on the results of petrographic and geochemical analysis indicates that assemblage of volcanic rocks Kamojang complex included in island arc calc-alkaline.

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