magmatism

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Magmatism And Geothermal Potential in Pandan Volcano East Java Indonesia

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ABSTRAK
Gunungapi Pandan adalah gunungapi yang terbentuk di atas batuan sedimen Tersier dari zona Kendeng yang tersedimentasikan di cekungan Jawa Timur. Selain menghasilkan potensi minyak bumi, seperti ladang minyak Cepu dan Bojonegoro, daerah ini juga menghasilkan potensi panas bumi. Sebagai sumber panas dari sistem panas bumi adalah batuan beku yang terbentuk dari proses magmatisme. Jenis batuan yang terbentuk oleh proses magmatisme dalam sistem panas bumi Pandan adalah basaltik-andesitik dan andesit hornblenda yang berafinitas afinitas kalk alkali K tinggi-sedang yang terletak di tatanan tektonik busur kepulauan. Interaksi batuan panas dari proses pasca magmatisme dengan cairan hidrotermal menghasilkan manifestasi mata air panas dan travertine kalsit di daerah penelitian. Prediksi suhu bawah permukaan air panas dari analisis geotermometer silika yang terkandung di Banyukuning dan Jarikasinan menunjukkan kesetimbangan kristobalit Beta (70 ºC) dan suhu kuarsa (120 ºC). Untuk mempelajari tentang magmatisme dan fluida panas bumi menggunakan metode petrografi dan analisis petrokimia (metode spektrometri fluoresensi sinar-X) untuk sampel batuan beku. Sedangkan untuk mempelajari jenis fluida dan geotermometer fluida geothermal menggunakan data dari peneliti sebelumnya. Studi penelitian ini diharapkan dapat memberikan informasi tambahan di bidang panas bumi dan magmatisme di daerah ini.

Kata kunci: magmatisme, gunungapi, geothermal, manifestasi

ABSTRACT
Pandan volcano is a volcano formed on Tertiary sedimentary rocks from the Kendeng zone deposited in the basin of East Java. In addition to generating petroleum potentials, such as Cepu and Bojonegoro oil fields, this area also generates geothermal potential. As a source of heat from the geothermal system is igneous rock formed from the magmatism process. The type of rock formed by the process of magmatism in the Pandan geothermal system is basaltic-andesitic and hornblende andesite are medium-high K calk alkaline affinity located in the island arc. The interaction of hot rock from post magmatism process with hydrothermal fluid resulted in the manifestation of hot springs and calcite travertine in the study area. Prediction of the subsurface temperature of hot water from geothermometer silica analysis contained in Banyukuning and Jarikasinan show cristobalite Beta equilibrium (70ºC) and quartz temperature (120ºC). To study about magmatism and geothermal fluid using petrographic method and petrochemical analysis (X-ray fluorescence spectrometry method) to the sample of igneous rock. While to study the fluid type and geothermometer of geothermal fluid using data from previous researchers. This research study is expected to provide additional information on the field of geothermal and magmatism in this area.

Keyword: magmatism, volcano, geothermal, manifestation

I. INTRODUCTION

Pandan volcano is located in Nganjuk East Java (Figure 1). The volcano has a geothermal potential of 52 MWe and is part of the geothermal potential in East Java of 911.5 MWe. The volcano is formed in Kendeng basin and according to Taylor and Karner (1983) the Kendeng basin is a typical back arc basin, but this basin is formed due to trench rollback. This is due to some by the generation or development of oceanic crust (Dewey, 1980, Karig, 1971), rifting of continental crust (Kobayashi, 1985), gravitational collapse built from continental collisions (Clift et al., 2003), or by the trapping of old oceanic crust behind the arc (Scholl et al., 1986). Meanwhile, according to Dickinson (1974) is a retro arc basin that forms as a compression foreland behind the volcanic arc. But Busby and Ingersoll (1995) defines this arc basin as ocean basin behind the intra-oceanic magmatic arc and continental basin behind the volcanic arc during the history of the continental Cenozoic volcanic arc of East Java. There is no evidence for new oceanic crust formed under the Kendeng Basin or for strike-slip fault. The basin was closer to back arc basin than the other and most of the "back arc basin" of the Sunda Shelf. The Kendeng basin is an asymmetrical depression, the deepest part of the basin is located just behind the arc, and the sediment volcanic and sedimentary rocks of the Eocene- Lower Miocene diluting to the edge of the Sunda Shelf (Waltham et al., 2008). Basin filling mainly comes from Southern Mountains Arc located on the south side of the basin (Smith et al., 2008) (see Figure 2).

When examined from the morphological formation, the evolution of the growth of this volcano moves from north to south and Mount Takuran is the youngest cone of the volcano complex. Pandan Volcano is Lower Pleistocene volcano (Bemmelen, 1949, Thoha et al., 2014) and this volcano grows covering Tertiary sedimentary rocks from the Kendeng Zone which is marine sediment and volcaniclastic sedimentary rocks. The geothermal manifestations formed by this volcano include hot springs and calcite travertine that can be found in the northern part of the Pandan volcano. The potential geothermal of this volcano will be very different with Quaternary volcanoes at the center of the Java Island, due to the age of the volcanoes formation. Therefore, by studying the characteristic of volcanoes both Tertiary and Quaternary, it is expected to provide additional data on the characterization of the geothermal field and magmatism in Java Island and can provide further direction on the exploration of geothermal.

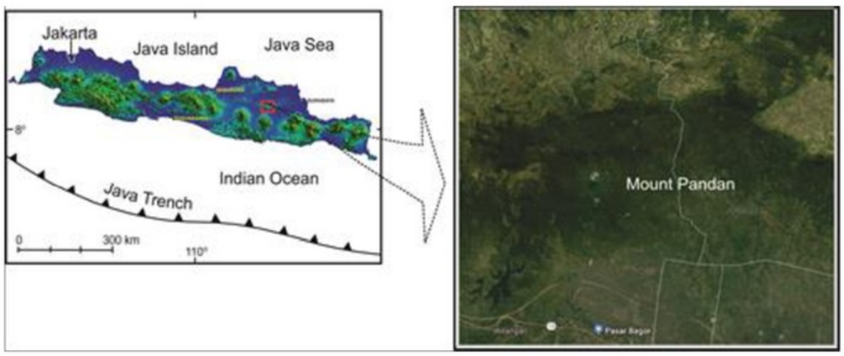

Figure 1. Location of research area at Mount Pandan East Java.

II. METHODS

The study of geothermal potential cannot be separated from the magmatism study. Because the role of magmatism in the geothermal system as a source of heat of the system. And to study the magmatism and reservoir rock type by using petrographic method and petrochemical analysis. The petrographic analysis was performed by observing volcanic rock samples under polarization microscope with 40 times magnification and the sample should be slashed first as thick as 0.03 mm. Petrographic analysis of rock samples include structure, texture, composition of mineralogy of rocks, affinity and tectonic environment of magma. The analysis was conducted on 4 volcanic rock samples namely basaltic andesite (P1) and hornblende andesite (P2, P2 and P4). While the petrochemical analysis yielded data of major element such as: SiO2, TiO2, Al2O3, Fe2O3, FeO, MnO, MgO, CaO, Na2O, K2O and P2O5. This analysis using XRF (X-ray fluorescence spectrometry) method was performed on volcanic rock samples in the research area. To study fluid type and fluid geothermometer using data from previous researchers. By doing this study it is expected to provide additional information on the magmatism and geothermal system in this area.

III. RESULT AND DISCUSSION

3.1. Geological Setting

Physiographically the research area according to Bemmelen (1949) is included in the Kendeng zone. This zone in the East Java basin is deposited Eocene-Miocene sediments consisting of marine sediments and volcanic sediments. In addition, the research areas traversed by reverse fault and folds have an east-west direction that is parallel to the axis of Java (Situmorang et al., 1976). This zone stretches from Mount Pandan eastward, ie Mojokerto until Madura. In the middle of this zone grew Pandan volcano which is above the Tertiary sediments. Kendeng zone is also a northern part of East Java basin area which has experienced two times uplift is on Miocene and during the Plio-Pleistocene. However, according to Sribudiyani et al. (2003) East Java has two main structural pattern, ie west - east or Sakala direction and northeast - southwest or Meratus direction. Bemmelen, (1949), Genevraye and Samuel, (1973) mentioned that in the study area deposited sediments in Pliocene to Pleistocene and the sediments were exposed both in the area between Pandan volcano and Mojokerto. Smyth (2005) describes the Early Cenozoikum stratigraphic of East Java provides a record of the cycle magmatic arc activity in East Java that begins from the Middle Eocene (42 Ma) and stop on Early

Miocene (20 Ma). The sedimentation process produces lithostratigraphy arrangement in the area of research by Pringgoprawiro and Sukido (1992) consists of Kalibeng Formation, Klitik Formation, Sonde Formation and Pucangan Formation. Kalibeng Formation aged Pliocene, consisting of Globigerina massive marl and marl clay which shows the structure of the bedding, convolute and interfingering with Atas Angin Member. Atas Angin Member is characterized by volcanic sandstones, tuffs, conglomerates and breccias. The upper part is continuously deposited the Klitik Formation composed by limestone and intersection marl and clay. The Pucangan Formation resulted from the eruption of active Wilis volcano on Lower Pleistocene age (Dyufjes, 1938 in Bemmelen, 1949) and then deposited volcanic sediments of Pandan volcano on 1.2 Ma (Pleistocene) consisting of laharic breccia (Lunt, 1991).

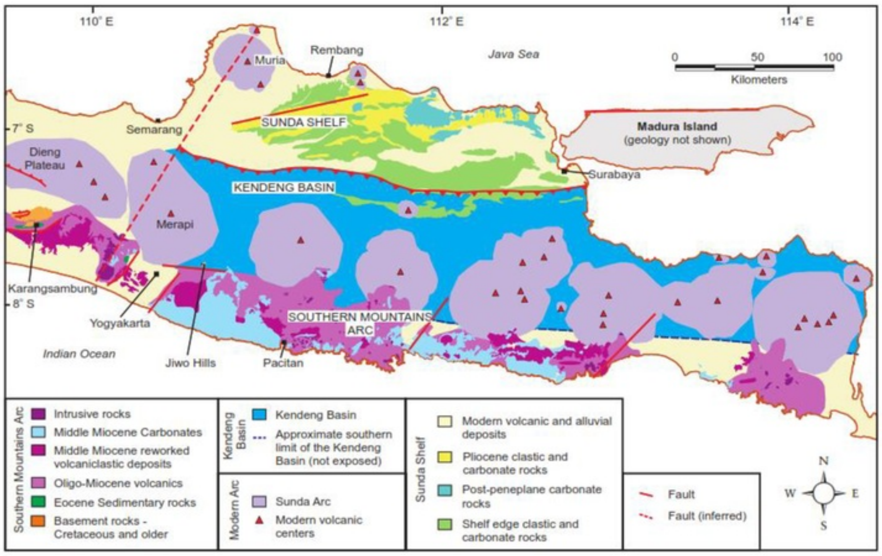

Figure 2. Simplified geological map of East Java, showing the main geological provinces and stratigraphic units (Smith *et al*., 2008).

3.2. Volcanic Rocks

From the results of petrographic observations of the 4 samples of volcanic rocks found in the research area, including: basaltic andesite (P1) and hornblende andesite (P2, P2 and P4). Characteristics of each volcanic rocks can be followed:

3.2.1. Basaltic Andesite

Basaltic Andesite is morphologically as a lava dome and microscopic observations show scoria structure, intergranular texture, porphyritic and hypocrystalline. Phenocrysts (80%) sized 0.2-1.2 mm composed by plagioclase, pyroxene (augite), and opaque minerals. Phenocrysts are floated on a groundmass consisting of volcanic glass and plagioclase microlites. Some opaque minerals were present as inclusion in plagioclase and pyroxene. Plagioclase present about 60% appears colorless, in the form of subhedral-anhedral, long prismatic, sized 0.2-1.2 mm. Present as phenocryst and groundmass. The composition of plagioclase microlite in the groundmass is Labradorite (An53). Plagioclase in general shows albite twining and some show zoning. Some phenocrysts show inclusion by opaque mineral and corrosion by groundmass. Pyroxene (augite) is present about 12%. Present as phenocryst and groundmass with thin prismatic or subhedral-anhderal shape with size 0.2-0.4 mm. Some opaque mineral inclusions are present in the body of pyroxene. Opaque minerals are present at about 3%, sometimes clustered in the groundmass and partially as minerals inclusion at pyroxene and plagioclase. Volcanic glass was present 25%, fine-sized as groundmass and with microlite plagioclase to form an intergranular texture. Petrography of thin section of this volcanic rock sample can be seen in Figure 3.

3.2.2. Hornblende Andesite

Hornblende andesite is a lava dome. Microscopically (Figure 4), the lavas show the structure of scoria and generally was hypocrystalline texture, porphyritic, pilotaxitic and scoria structure. The phenocrysts (65-75%) consist of plagioclase, pyroxene (augite), hornblende and opaque minerals measuring 0.2-1.2 mm. Phenocrysts were embedded in the groundmass of volcanic glass and plagioclase microlites. Some phenocrysts appear to be inclusive of opaque minerals. Plagioclase (50-52-%) appears colorless, in the form of subhedral-anhedral, long prismatic, 0.2-1.2 mm in size. Present as phenocryst and groundmass. As a plagioclase microlites compose Andesine type (An47-An49). Plagioclase shows an albite twin and some zoning. Some phenocrysts show corrosion by groundmass and inclusion by opaque minerals. Hornblende (8-12%), present as phenocryst and groundmass, is subhedral-anhedral in size 0.2-0.4 mm. Some phenocrysts show oxidized by iron oxide minerals. Pyroxene (augite, 5-8%), as phenocryst and groundmass. Pyroxene as a short prismatic shape or subhedral-anhedral sized 0.2-0.4 mm. Opaque minerals present pyroxene inclusions. Opaque minerals are present at about 5%, sometimes clustered within the groundmass and partially as minerals inclusion at pyroxene and plagioclase. Volcanic glass (25-30%) comes as a smooth groundmass. Together with plagioclase microlite and opaque minerals form pilotaxitic textures.

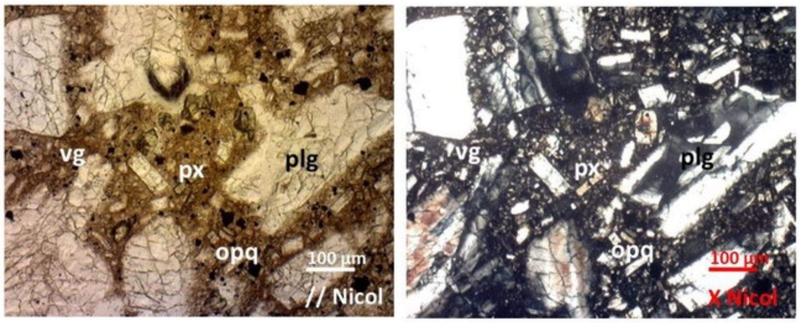

Figure 3. Shows basaltic andesite lava (P1) with intergranular texture composed by plagioclase (plg), pyroxene (px) in groundmass of microlite plagioclase and volcanic glass (vg).

3.3. Volcanic Rocks Geochemistry

Pandan vulcano has several eruption centers, but in this study represented by two samples from lava domes, ie samples P1 and P4. These volcanic rocks are basaltic andesite and hornblende andesite. Basaltic andesite volcanic rocks have SiO2 (51.82%), total Fe2O3 (11.65%) and MgO (7.66%) higher than hornblende andesite containing SiO2 (57.18%), Fe2O3 (7.16%) and MgO (7.66%). However, the Na2O element (2.81%), K2O (0.81%) of basaltic-andesite is lower than the andesite hornblende which includes elements of Na2O (3.37%) and K2O (2.47%). The tabulation of the chemical elements of the two volcanic rocks is presented in Table 1. The result of plot of SiO2 element to total Na2O + K2O from Tas Le Maitre USGS diagram (1989) shows that the type of volcanic rock of research area includes basaltic andesite and hornblende andesite (Figure 5). While the result of plot of SiO2 to K2O from Pecerrillo and Taylor diagram (1976) shows that the type of volcanic rock of the study area includes medium-high K calc-alkaline series (Figure 6).

3.4. Magmatism

This magmatic arc in Java Island as described by Soeria-Atmadja et al. (1994) occupies the southern and central parts of Java Island. This magmatic arc stretches from the west-east composed of tholeiitic-calk-alkali affinity of volcanic rocks (Old Andesite Formation of Late Eocene-Early Miocene), Late Miocene-Pliocene of magmatic arc calk-alkaline affinity and Quaternary. In East Java, a series of Quaternary volcanoes form a straight-line direction west-east.

The results of the petrographic observations of Pandan volcano samples showed that the general composition phenocrysts and groundmass form high intense porphyritic texture around 65-80% (Figure 3 and 4). Phenocryst consists of plagioclase, pyroxene, hornblende and opaque minerals and according to Ewart (1982) and Wilson (1989) explains that the presence of these phenocryst mineral abundances is characteristic of island arcs. In addition, based on the results of plot Pandan volcano petrochemical data on Peccerrillo and Taylor diagrams (1976) included in medium-high K calk-alkaline series, so that volcanic rocks group of Pandan volcano was formed in island arc tectonic environments. This magmatic arc was formed on Plio-Pleistocene.

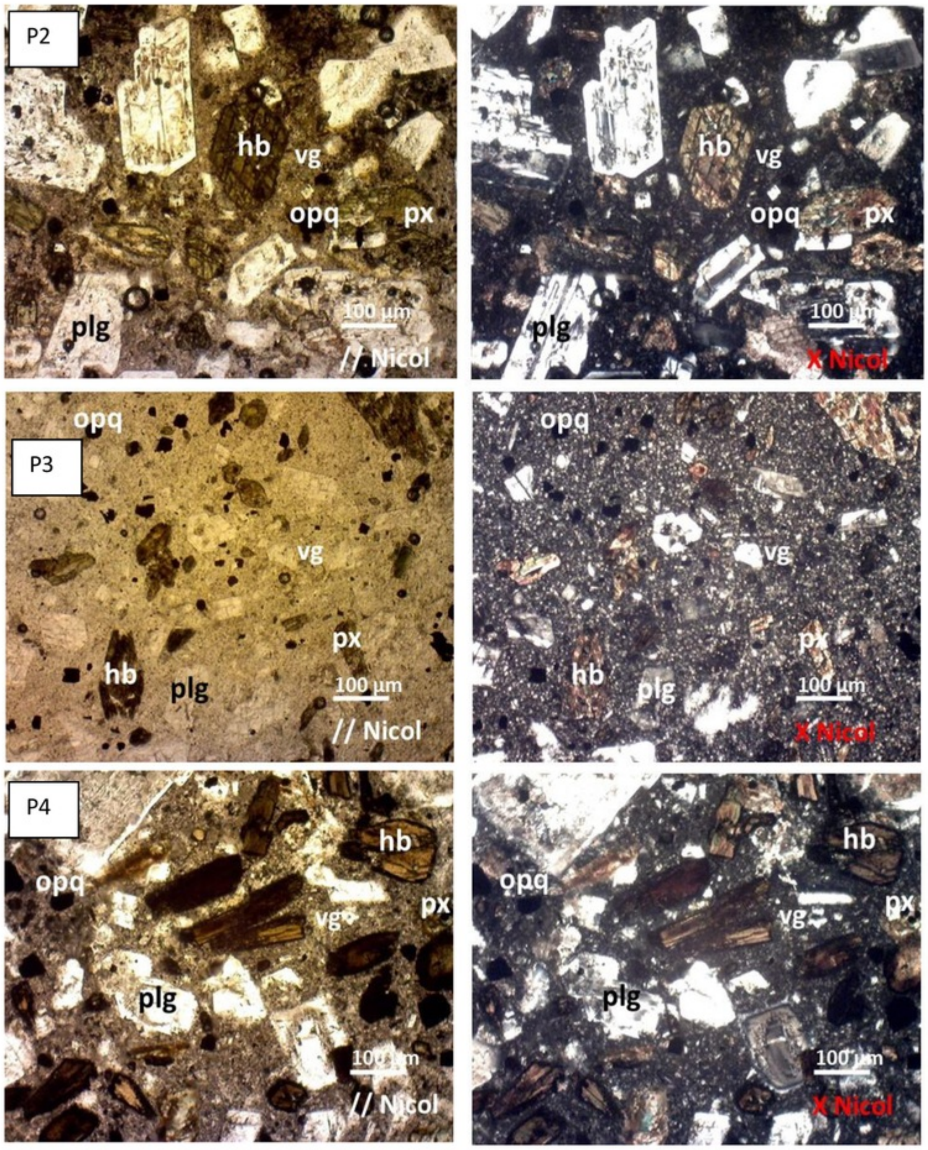

Figure 4. Shows hornblende andesite lavas (P2, P3 dan P4) with porphyritic texture composed by plagioclase (plg), pyroxene (px), hornblende (hb) in groundmass of plagioclase microlite and volcanic glass (vg). Pilotaxitic texture was seen in P3 and P4 samples.

Table 1. Chemical elements of volcanic rocks of Pandan volcano.

Elements (wt%)	P1	P2
SiO_2	51.82	57.18
TiO_2	0.86	0.58
Al_2O_3	15.76	16.6
Fe_2O_3	1.51	1.03
FeO	9.06	6.15
MnO	0.17	0.23
MgO	7.66	1.45
CaO	9.34	9.63
Na_2O	2.81	3.37
K_2O	0.81	2.47
P_2O_5	0.13	0.26
Norm		
Q		4.68
or	4.77	14.70
ab	25.24	30.41
an	27.94	23.04
di	13.98	18.67
hy	20.79	5.99
ol	4.11	
mt	1.71	1.17
il	1.19	0.81

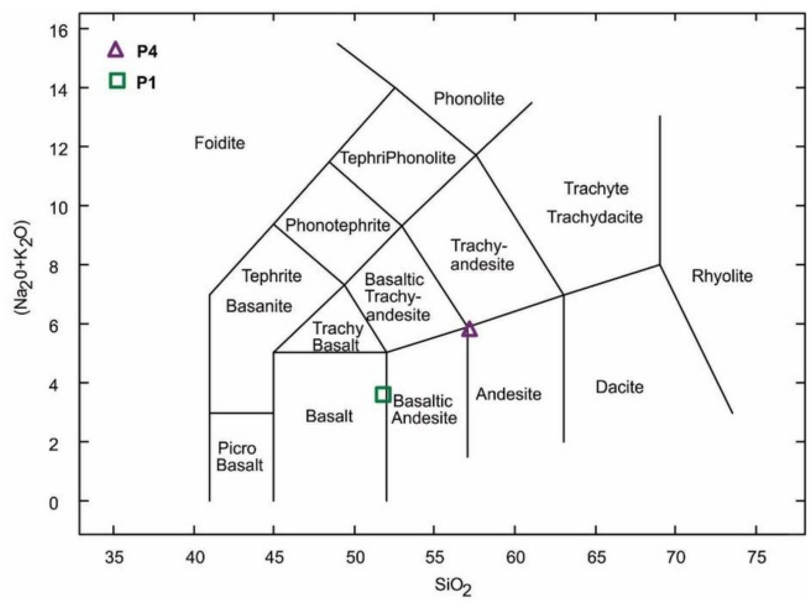

Figure 5. Demonstrate the result of plotting volcanic rock of Pandan volcano in the diagram of Tas Le Maitre USGS (1989) shows that volcanic rock types include basaltic andesite and hornblende andesite.

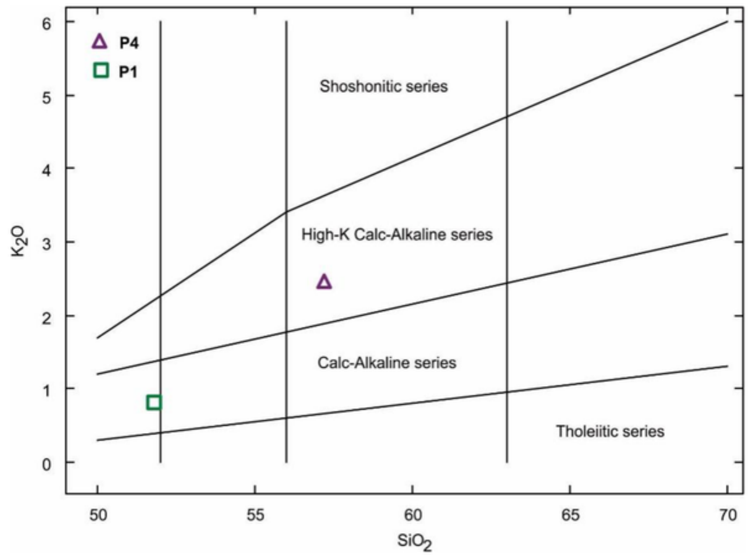

Figure 6. The results of ploting Pandan volcanic rocks on Peccerrillo and Taylor diagrams (1976) including medium and high-K calc-alkaline series.

3.5. Fluids Geochemistry

Hochstein (1995) explain that geothermal system is a convective heat transfer system located in the upper crust that transferring heat from a heat source to the surface. The heat transfer involves fluids (convection) and without fluids (conduction). Geothermal systems involving fluids, such as meteoric water or with magmatic fluids are referred to as hydrothermal systems (Hochstein and Browne, 2000). Evidence of this geothermal activity is manifestations in the surface (Saptadji, 2008). This manifestation can estimate the amount of thermal energy output from the subsurface reservoir. Lawless et al. (1995) explains that the purpose of geochemical methods is used to assess the possibility of developing geothermal resources, such as resource size, reservoir heat and permeability formation. Geochemical data required are chemical manifestations of hot water, isotopes, soil chemistry and soil gas. While the use of anion components Cl, SO4 and HCO3 is used to determine the composition of geothermal fluids. In addition, the element ratio of Cl-HCO3-SO4 is used to determine the type of geothermal fluids (Giggenbach, 1988). In the research area evidence geothermal manifestations found are hot springs and travertine calcite. The geothermometer analysis in this study uses data that has been written by Sutanto et al. (2014) presented in Table 2.

Chemical analysis of geothermal hot water can be used to determine the type of fluids and fluids composition of the geothermal system. Water samples in the study area were taken at two hot springs, ie at Jarikasinan and Banyukuning locations. The result of plot the water chemistry data in Cl-HCO3-SO4 diagram (Figure 7) shows that the type of water or geothermal fluid indicates the type of bicarbonate water or peripheral water. This type of bicarbonate hot water has a HCO3 concentration of 891.57-939.62 mg/L, Cl (316.25-557.65 mg/L) and SO4 of 190-229.04 mg/L.

3.6. Water geothermometer

Water geothermometer calculations are used to determine the temperature of the subsurface reservoir. In this geothermometer analysis use the Na/1000-K/100-VMg diagram (Figure 8) and SiO_2 mg/L diagram to log (K_2/Mg) as shown in Figure 9. The hot water chemistry samples obtained from the field are then plotted on the diagrams of Figure 7. The plot results of the hot water samples in Figure 8 show that the JK sample lies in the partial equilibrium region with a temperature of 160°C. The composition of hot water in this sample shows the high element of Na (746.10 mg/L), K (72.60 mg/L) and Mg (9.00 mg/L). While other water samples (BK) lies in the area of immature waters. BK hot water samples were dissolved with shallow groundwater, thus containing high Mg (71.50 mg/L). This example of water according to Giggenbach (1988) cannot be used as a geothermometry of reservoir temperature estimation. The result of plot hot water sample in SiO_2 mg/kg diagram to log (K_2/Mg) indicates that the sample of BK is at balance of Beta Cristobalite temperature (70°C), while the JK sample is in Quartz formation at 120°C (Figure 9). From the calculation of silica geothermometer can provide the minimum reservoir temperature range of 70-120°C.

Table 2. Chemical analysis of hot springs (Sutanto *et al.*, 2014).

	Jarikasinan (JK)	Banyukuning (BK)
pH	6.99	6.75
DHL	5270.00	3020.00
SiO_2	95.69	168.23
B	29.80	8.56
Al_3^+	0.00	0.09
Fe_3^+	0.02	0.10
Ca_2^+	32.04	128.10
Mg_2^+	9.00	71.50
Na^+	746.10	289.20
K^+	72.60	31.20
Li^+	4.70	1.35
As_3^+	0.00	0.00
NH_4^+	24.28	4.86
F^-	0.52	0.00
Cl^-	557.65	316.25
SO_4^{2-}	229.04	18.99
HCO_3^-	939.62	891.57
CO_3^-	0.00	0.00

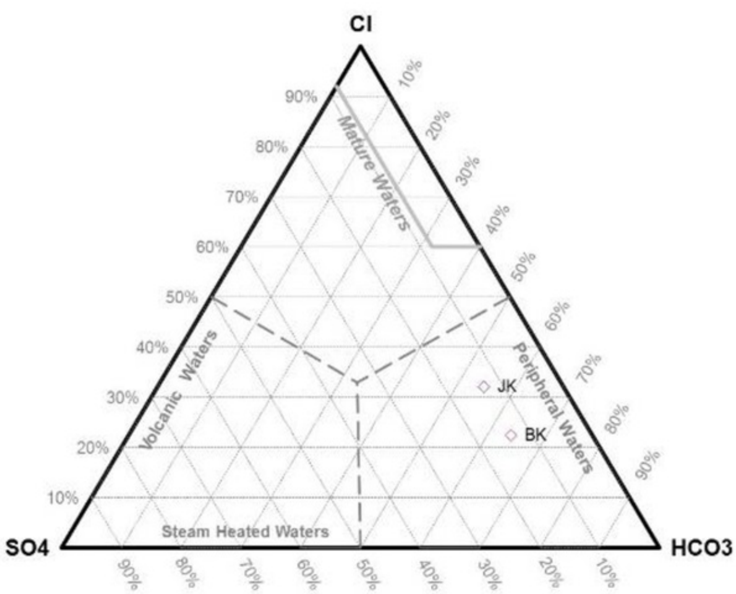

Figure 7. The result of plot of water chemistry data of Pandan volcano area on Cl-HCO_3-SO_4 diagram. The sample of the research area is located on the peripheral water area.

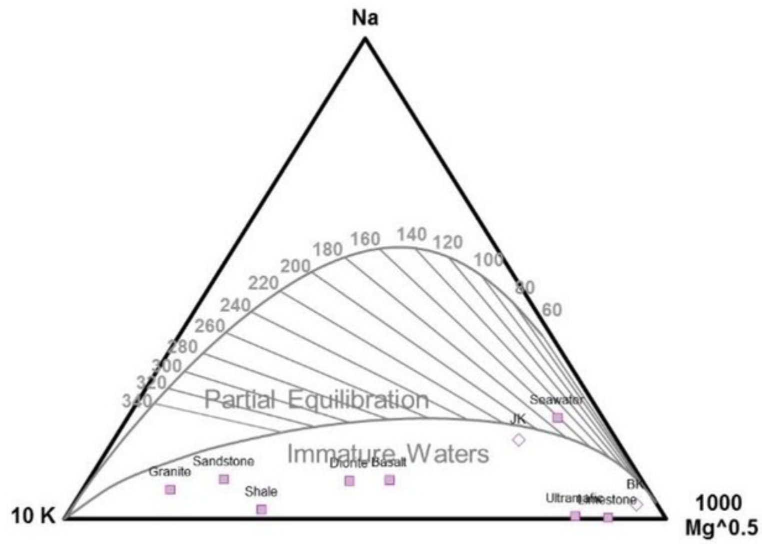

Figure 8. Results plotted of hot water samples on Na/1000-K/100-√Mg diagram. The sample of Jarikasinan (JK) lies in the partial equilibrium region, while the Banyukuning (BK) sample is included in immature water area.

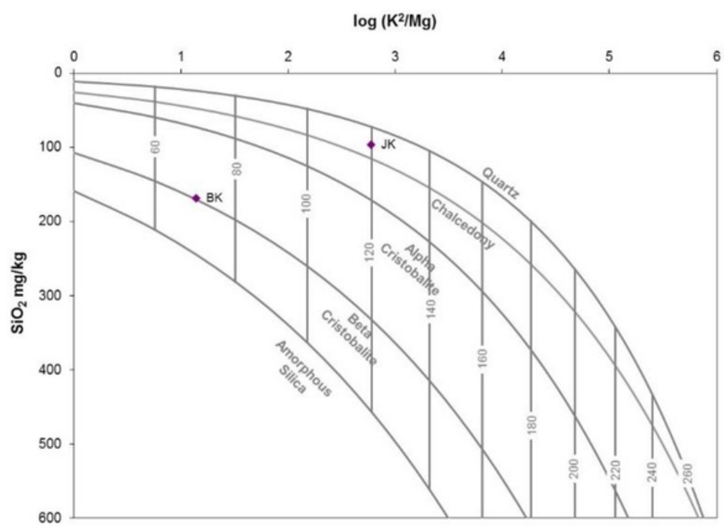

Figure 9. Results of hot water samples plot on SiO_2 mg/kg diagram to log (K_2/Mg). The sample of Jarikasinan (JK) has subsurface temperature of 120ºC, while the geothermometer of Banyukuning (BK) sample is 70ºC.

IV. Conclusions

Pandan geothermal system geologically lies in island arc tectonic environments with medium-high K calk-alkaline magmatic affinity. This magmatic affinity forms Pandan volcano on 1.2 Ma (Pleistocene) with strato volcano type. Morphologically seen the southern part of this volcano complex is younger. The type of rock that erupted by this volcano in the form of lavas, pyroclastics and tuff breccias that compose from basaltic andesitic to hornblende andesite.

Based on geochemical analysis of water, the type of hot water of Banyukuning and Jarikasinan areas including bicarbonate water types. The type of water shows the high concentration of HCO3 elements. However, the result of water geothermometer analysis shows that reservoir temperature is 70o from Banyukuning hot water, while reservoir temperature of 120°C is owned by hot water Jarikasinan sample.

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