INVESTIGATING GEOTHERMAL POTENTIAL IN RANAU LAKE, LAMPUNG: A MULTIFACETED APPROACH USING FAULT DENSITY AND GEOCHEMICAL ANALYSIS

Emily Parker[1], Lucas Brown[1], Olivia Green[2], Noah Adams[3], and Sophie Turner*
Geology Study Program of Engineering Faculty of Sriwijaya University
Jl. Srijaya Negara Bukit Besar, Palembang, South Sumatra, 30139

ABSTRACT

Conventional energy is currently decreasing continuously so that the development of alternative energy is needed. Promising alternative energy to develop is geothermal energy. Indonesia has a geothermal potential of 29.215 GWe, one of them which is on Ranau Lake. Administratively, Ranau Lake is located in West Lampung District, Lampung Province and South Ogan Komering Ulu District, South Sumatra Province. This study aims to identify geothermal potential based on fault and fracture density, petrography, and water geochemistry analysis. The methods used in this study are literature studies, geospatial analysis, field observations, laboratory analysis, and interpretation. The literature study uses a qualitative approach. Geographic Information System based geospatial analysis can be identified using the Fault and Fracture Density (FFD) method, lineament analysis of SRTM, and topographic data. By using those methods, the existing of fractures and possible levels of the areas that are recharged and discharge zones for geothermal might be predicted. Field observations include observing the appearance of rocks megascopically and the presence of geothermal manifestations. The results of the petrographic analysis of rock samples are dominated by mineral plagioclase, pyroxene, and biotite. Data that is analyzed water geochemistry is a manifestation that exists on the surface of the study area, namely hot spring. Water geochemistry data are integrated to determine the characteristics of water, temperature, and pH. Water sampling is carried out in areas of geothermal manifestations, such as Kota Batu, Seminung 1, Seminung 2, and Lombok. Surface temperature in the study area varies from 43-57°C and the pH value is 4.8-7.1. Laboratory analysis shows that water samples have high bicarbonate concentrations and include bicarbonate water types (HCO_3). The presence of manifestations and the results of FFD analysis, it shows that the research area has the potential to become the next target of geothermal exploration.

Keywords: fault and fracture density, geothermal, petrography, ranau, water geochemistry

INTRODUCTION

Indonesia is an archipelago with a very large population so that a shortage of electricity supply often occurs throughout the region. This has become a serious problem, it can lead to obstacles in progress in the fields of industry, mining, livestock, and others. That way, alternative energy is needed as a substitute for fossil energy for electricity generation, one of which is geothermal energy. Geothermal energy is renewable energy that is considered to have economic value and environmentally friendly. According to Suparno (2009), geothermal energy is natural heat formed in the earth's crust that occurs by convection or conduction. According to Article 1 of Law No. 27, 2003 concerning geothermal energy, geothermal energy is a source of heat energy contained in hot water, water vapor and rocks along with related minerals and other gases, all of which are genetically inseparable in geothermal systems. Indonesia's geothermal potential is estimated at 28.5 GWe spread throughout Indonesia with a total of around 265 locations (Center for Geological Resources, 2009). Sumatra Island is one of the islands that has geothermal energy potential its because Sumatra Island located on an active plate. The presence of collision activity between the Eurasian Plate and the Indo-Australian Plate forms a subduction zone along Sumatra Island, known as Bukit Barisan. The existence of an active mountain path along Sumatra makes Sumatra have high geothermal potential. One of the regions in Sumatra that has geothermal energy potential is South Sumatra. According to Kusuma et al. (2005), a geothermal potential in South Sumatra is 1,911 MW or 13.83% of the resources in Sumatra or 7.04% of national potential. So that the development and research on geothermal manifestations in South Sumatra is an interesting thing to do. One area that has the potential for geothermal energy is located in Lake Ranau, West Lampung Regency, Lampung Province and Ogan Komering Ulu District, South Sumatra Province. Ranau Lake is a volcanic lake located along Bukit Barisan. This study aims to evaluate the geothermal potential in Lake Ranau based on analysis of Fault and Fracture Density (FFD), rock petrography, and water geochemistry.

REGIONAL GEOLOGY

Ranau Lake is a pull-apart basin formed by the transitional regime of the Semangko fault. The increase in the Bukit Barisan in Late Neogene increased magmatism activity along Sumatra and formed volcanoes along the Semangko fault. The volcanic formation in the active fault leaves a liquid magma that is strongly suspected of being a source of geothermal energy in the lake Ranau. The presence of geothermal energy is indicated by hot springs in several places around Seminung's feet. According to Kusuma et.al., (2015), the oldest rocks in the area are volcanic rocks of the Tertiary Hulusimpang (Tomh) Formation with andesite and basal lava species, volcanic breccias and tuffs which are embedded in sandstones. Some of the rock from this formation has been altered, with chlorinated and propylated, and mineralized sulfides and gold. The Ranau (QTr) formation deposited in the land environment from sub-aerial volcanic and overlapping is not aligned with the unit below, composed of riolytic tuffs, tuffs, welded tuffs and claystones. Other Quaternary volcanic deposits are tuffs and volcanic breccia (Qhv) with the composition of andesite lava, lava and tufa breccia - basalt and general orientation of alignment are N 142 ° E, almost in line with the Sumatra Island regional structural system which has dextral direction. Overall the morphology of the area of Lake Ranau consists of plain to the mountain with different rock characteristics and characteristics. Stratigraphically, rocks are dominated by volcanic rocks which are the result of Tertiary Mountain old volcanic products of Kukusan Mountain and Lake Ranau products which are overlapped by volcanic rocks from the products of the Quaternary Mount Seminung (Figure 1).

The process of forming rock units in this area begins at the Tertiary time which forms volcanic rocks in the form of andesite and tufa lava with quartz veins, calcite and magnetite which fill fractured cavities and have been modified composite are pyroclastic flows scattered in the middle of the investigation. This unit overlaps inconsistently old lava rocks. Furthermore, lava, breccias and lava products from Mount Kukusan are located in the west. This unit overlaps the alignment of old lava units and has a thickness of about 20-50 cm. This unit age is estimated to form during the Pliocene or Late Quaternary period. Semangko fault activities that form anechelon patterns result in the formation of Mount Seminung. This Gunung Seminung is interpreted to be a source of heat from the Lake Ranau geothermal system. The main structure in the prospect of Lake Ranau is the normal Talang Kedu Fault, Kotabatu and Wai Uluhan which are trending northeast-southeast, besides that there is a Lombok fault that has a relatively North-South direction. Based on its genes, the Wai Uluhan fault is a minor component of the Sumatra fault system, while the Talang Kedu and Kotabatu faults are re-juvenile faults from the old pattern that deforms rocks under the Seminung volcano product rock unit. Geothermal manifestations in this prospect are closely related to the formation of the three main faults above and the Lombok fault which traverses north-south.

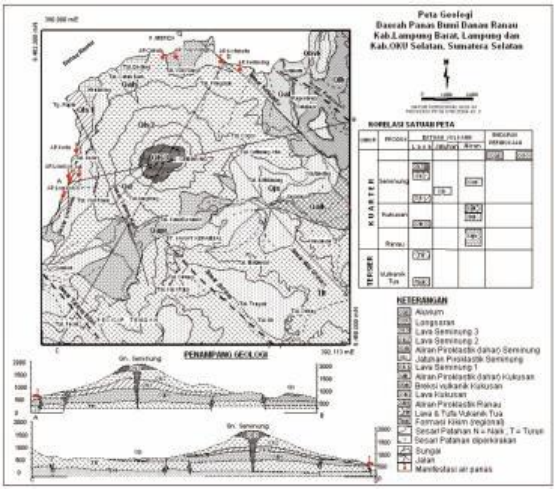


Figure 1: Regional Geological Map in Ranau Lake, Lampung-South Sumatra (Kusuma et.al., 2015)

METHODS

The methods used in this study are literature studies, geospatial analysis, field observations, laboratory analysis, and interpretation. The literature study uses a qualitative approach. Geospatial analysis based on Geographic Information Systems can be combined using the Fault and Fracture Density (FFD) method, lineament analysis, and topographic data. This method can consider the presence of fractures and the level of expenditure of the area being refilled and the geothermal release zone can be predicted. The research methodology used is the analysis of outline density based on Thanoun R. G. (2013) with a basic map in the form of the Image of Shuttle Radar Topography Missile (SRTM) in the form of Digital Elevation Model (DEM) (Nugroho, 2016). The SRTM map of Ranau Lake area is then extracted through a shaded relief process using the ArcGIS 10.4 application, based on 4 different light azimuths that are 0 degrees, 45 degrees, 90 degrees, and 315 degrees with altitude 45 degrees. Then the top assessment is carried out, then the value of the length is calculated. The length of this extraction line depends on the value of the parameters made at the line making stage in PCI Geomatica software. This modular algorithm consists of three layers, namely edge detection, thresholding and curve extraction. LINE module on PCI Geomatica application extracts line lines from images by changing this linear feature in vector form using six supported parameters, namely (RADI, GTHR, LTHR, FTHR, ATHR, and DTHR (Sarp, 2005). Each area will show a different lineament intensity areas with large

lineament densities, will have a large lineament density value so that it can be an area that is assumed to have the greatest prospect as a geothermal fluid discharge path. Field observations included observing rocks in a megascopic manner and sampling geothermal manifestations. Taking hot spring samples in accordance with the procedure from Nichols (1993). Next, conduct petrographic analysis of rocks to determine the characteristics of rocks, mineral appearance, and Ganesha from these rocks. Laboratory analysis was carried out to determine the geochemical content of water, geochemical data was used to determine the type of water using the Giggenbach (1991) method, and reservoir temperature using the method of Giggenbach (1988).

RESULTS

The results of the study were lineament analysis, Fault and Fracture Density (FFD), geothermal manifestation, petrographic analysis, and water geochemistry.

Lineament Analysis

Based on the results of processing DEM SRTM image data with a resolution of 30m, straightness pattern analysis has been carried out with four irradiation perspectives using ArcGis 10.4 and PCI Geomatica applications with 0, 45, 90 and 315 degrees azimuth values (Figure 2).

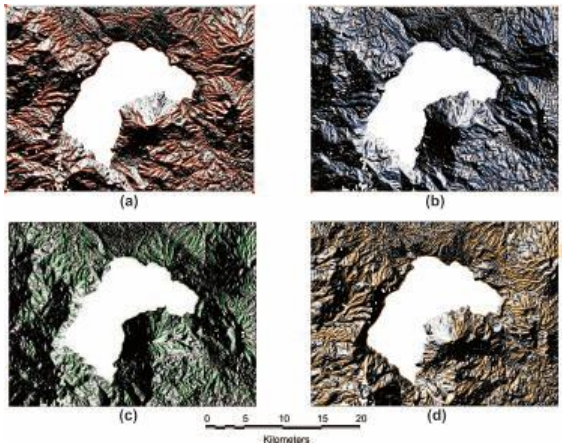


Figure 2: Lineament analysis with combination of light directed 0 (a), 45 (b), 90 (c), and 315 (d) degrees using the altitude 45.

For determining the direction of each line, the conversion is in the form of a rose diagram of each line pattern. The rose diagram will show the direction of lineament formed in the research area based on vector parameters in the form of direction and magnitude in the form of a particular direction. All SRTM DEM 30m image lighting data with different azimuth angles produce different lineament directions. The lineament pattern map with azimuth 0 lighting results in the dominant direction of the west-east lineament, the lineament pattern with azimuth lighting 45 produces the dominant direction of the northeast-southwest line, the alignment pattern with azimuth lighting 90 produces the dominant direction of north-south lineament, and the line pattern with lighting 315 azimuth produces the dominant direction of west-east lineament (Figure 3)

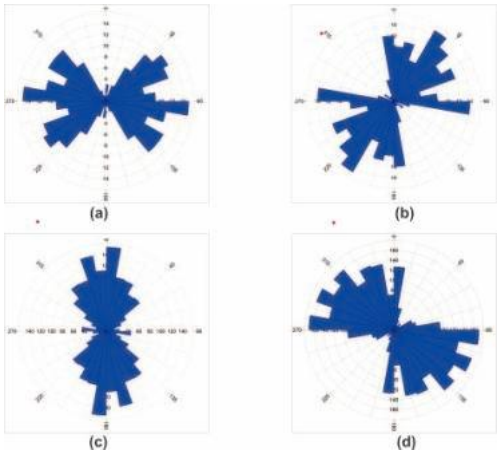


Figure 3: Rose diagram with light 0 degree (a), 45 degree (b), 90 degree (c), 315 degree (d).

The results of combination with four light perspectives show that main trend in the developing area of Ranau Lake has a north-south direction (N-S) (Figure 4). The direction of this lineament is interpreted as a secondary structure resulting from the movement of the Sumatran Fault System's regional primary structure with the NW-SE direction. However, a small number of regions have lineament that is in harmony with the primary structure.

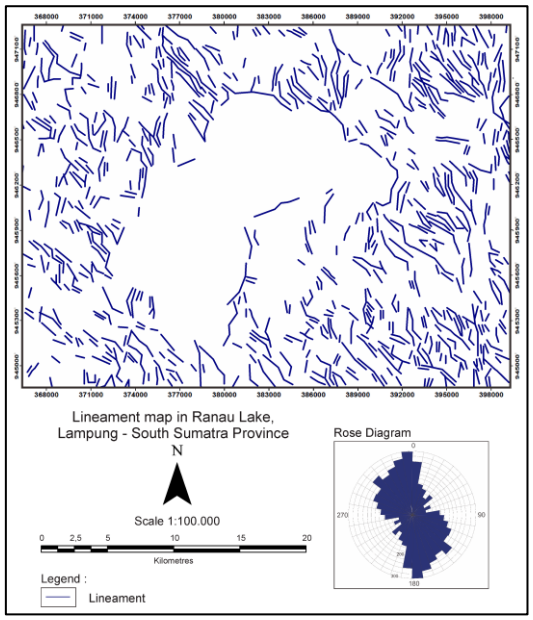
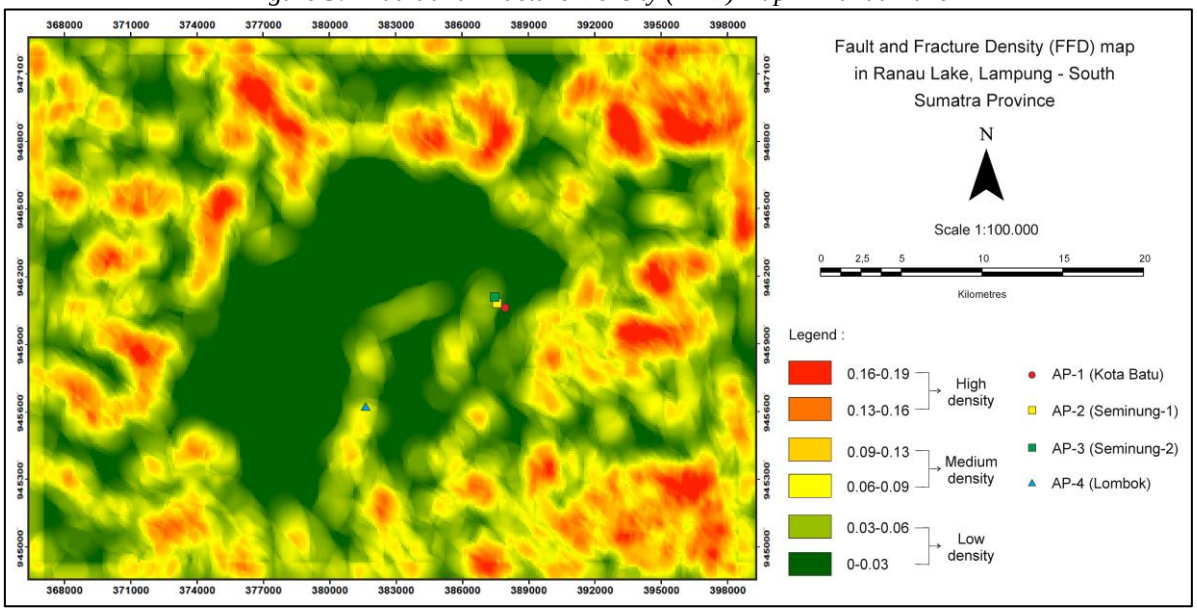


Figure 4: Lineament map using combination with four light perspectives.

Fault and Fracture Density (FFD)

The making of FFD map is based on the overlay of the four alignment patterns. Then this line pattern is grouped into several regions that have the highest straightness intensity. Based on the calculation of density values using the FFD method, the Ranau Lake is group into three density classes, namely low density (0-0.06 km/km²) which is shown in dark green-light green, medium density (0.06-0.13 km/km²) with yellow-young orange, and high density (0.13-0.19 km/km²) indicated by orange-red colour (Figure 5). Then, the results of the FFD zone analysis were compared with geothermal manifestation from the field observations. The location of geothermal manifestations is in the area with lineament. Geothermal manifestations are traversed by faults or fractures in regions with low to medium density value.

Figure 5: Fault and Fracture Density (FFD) map in Ranau Lake



Geothermal Manifestations

The results of field observations found four locations of geothermal manifestations around Mount Seminung, namely Kota Batu (AP-1), Seminung 1 (AP-2), Seminung 2 (AP-3), and Lombok (AP-4) (Figure 6). Geothermal manifestations are found in the form of hot springs with temperatures ranging from 43-57 ° C with a pH value of 4.8-7.1 (Table 1). Hot eyes are found in clear conditions with hot steam around it.

Figure 6: Location of geothermal manifestation in Ranau Lake

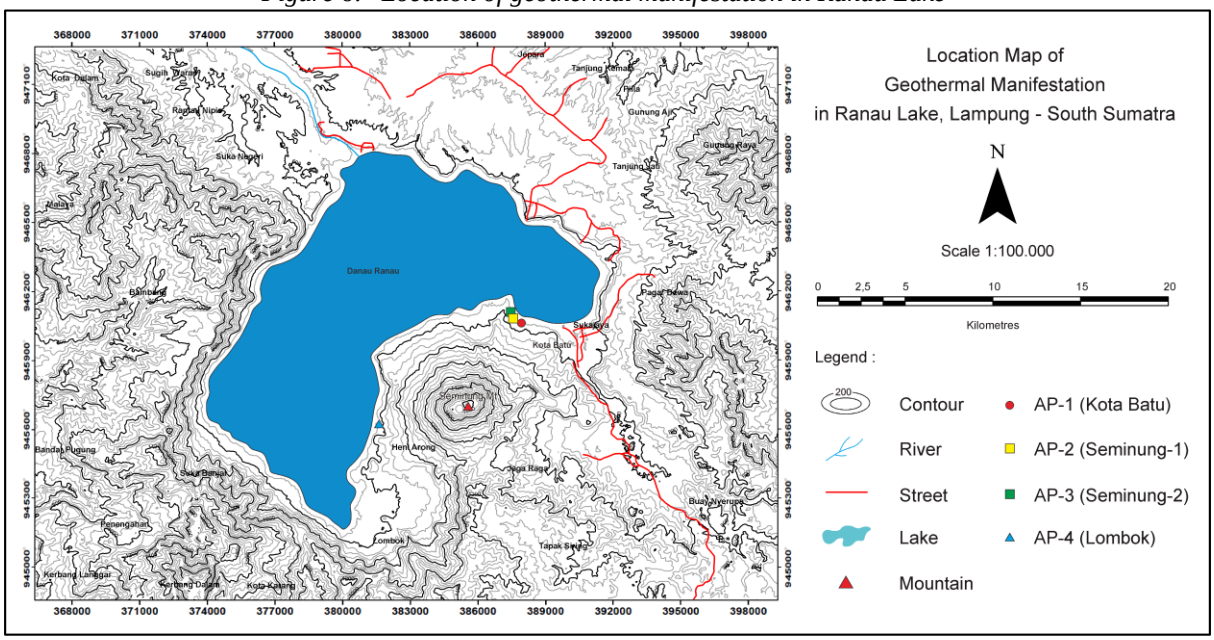


Table 1: The characteristics of geothermal manifestations in research area

No	Coordinate (48M)	Sample Code	Manifestation	Sample	Temperature (°C)	pH
1	387460 9460345	AP-1 (Kota Batu)	Hotspring	Water	43	6,8
2	387120 9460504	AP-2 (Seminung-1)	Hotspring	Water	45	6.9
3	386840 9460603	AP-3 (Seminung-2)	Hotspring	Water	57	7,1
4	381877 9456771	RL-4 (Lombok)	Hotspring	Water	55	6,8

Petrography Analysis

The lithology found at the observation site is volcanic andesite and pyroclastic rocks from the volcanic activity of Mount Seminung. Petrography analysis was carried out on four rock samples found in the study area to determine the mineral composition and the rock genesis.

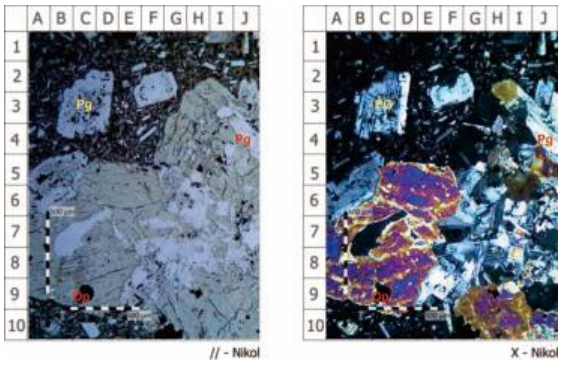


Figure 7: Thin section of andesite

Figure 7 shows thin sections of volcanic igneous (andesite), black and white, holocrystalline, ofytic, composed of phenocryst plagioclase and pyroxen >5 mm, as well as basic mass of plagiocalse, pyroxen and quartz fractions <0.5 mm, mineral composition plgioclase, pyroxene, opaque minerals, and clay.

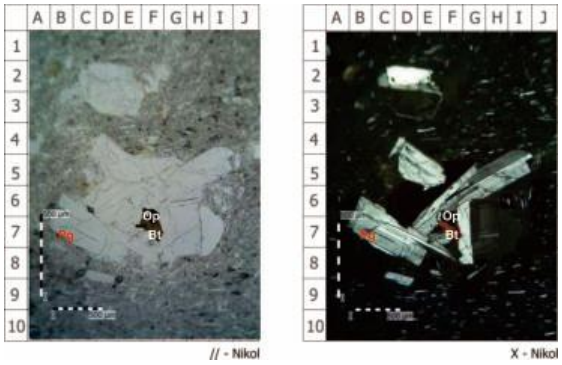


Figure 8: Thin section of welded tuff

Figure 8 shows welded tuff incisions have blackish gray color, hypocrystalline texture, plagioclase arranged as phenocryst >4 mm, base mass <0.1 mm, mineral composition consists of plagioclase, pyroxene, clay, and opaque minerals.

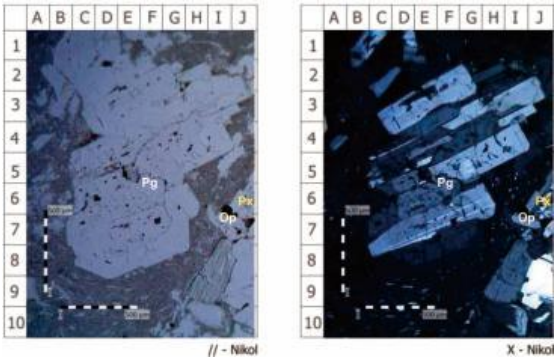


Figure 9: Thin section of andesite

Figure 9 shows thin section of volcanic igneous (andesite), brownish gray, hypocrystalline, flow texture, composed of phenocryst plagioclase and pyroxene 6> mm as well as the base mass of plagiocalse fractions and clay minerals <0.1 mm, mineral composition of plgioclase, pyroxene, opaque minerals, and clay.

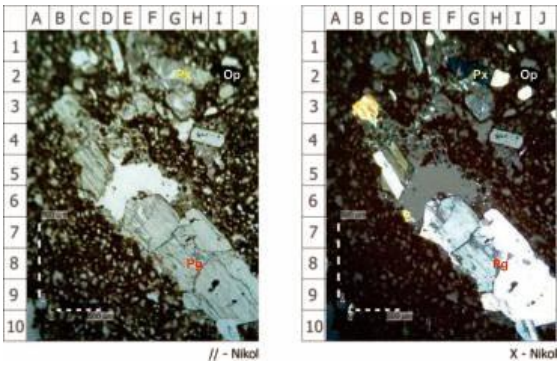


Figure 10: Thin section of andesite

Figure 10 show the volcanic igneous (andesite) incision, brownish red, hypocrystalline, composed of clay minerals as a base mass <0.1 m, and as phenocrysts namely plagioclase and pyroxene >4 mm, plagioclase mineral composition, pyroxene, opaque minerals, clay minerals, there are gas holes in the base mass and phenocrysts.

Based on the results of petrographic analysis, it is dominated by plagioclase (Pg), pyroxene (Px), and biotite (Bt) minerals, which are minerals far below the surface which can strengthen the evidence of remaining magma sources from the formation of Seminung volcano which is a geothermal energy

source which is controlled by fractures due to tectonics.

Water Geochemistry

Taking water samples at all four observation locations was carried out by laboratory analysis to determine the type of water. The analysis was to determine the contents of cations and anions contained in samples of hot water (Table 2).

Table 2: The result of data of geochemical water sample in research area

K & A*	Manifestation			
	AP-1	AP-2	AP-3	AP-4
Mg^{2+}	45,89	14,06	12,39	32,45
Na^{+}	65,00	50,00	80,00	75,00
K^{+}	9,00	16,00	17,00	9,00
Cl^{-}	7,76	9,83	25,29	15,02
SO_4^{2-}	1,95	1,95	0,58	2,35
HCO_3^{-}	87,35	88,22	74,12	82,63
Ca^{2+}	12,30	3,92	3,14	12,50

*Explanation : K = Kations, A= Anions
(Hastuti et.al., 2012, Unpublished)

Based on the triangle diagram Cl^{-}, SO_4, HCO_3^{-}, the location of Kota Batu (AP-1), Seminung 1 (AP-2), Seminung 2 (AP-3), and Lombok (AP-4) is a type of bicarbonate water. (Figure 11). This is indicated by the higher concentration of bicarbonate ions. This type of water has the main ion content in the form of HCO_3^{-} and a pH value that is close to neutral in reaction to local rocks. Hot water found is indicated to come from a water source containing chloride. Thus, hot water found has been mixed with surface water that is pre dominantly carbonate.

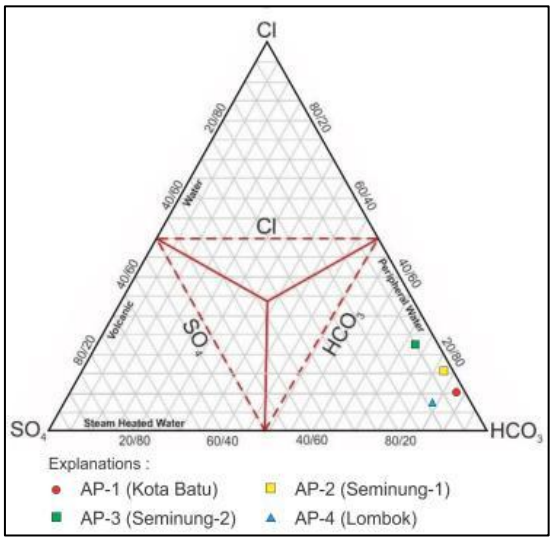


Figure 11: Ternary plot of the major anions Cl^{-},SO_4,HCO_3^{-} for the determination of hot water manifestation type (Hastuti et.al., 2012, Unpublished).

Based on the results of the triangle diagram Cl^{-}, SO_4, HCO_3^{-} and geothermometer calculations from the Na^{+} diagram, K^{+}, Mg^{2+} indicates that the location of Batu City (AP-1), Seminung 1 (AP-2), Seminung 2 (AP-3), and Lombok (AP-4) is a reservoir with bicarbonate water type and immature water conditions (Figure 12). Immature water conditions indicate that hot water has been diluted by surface water with a large concentration of magnesium in meteoric water compared to water originating from fluid flows with potassium content. According to Salaga (2009), water with bicarbonate type is not good to use because the fluid in the manifestation is not directly related to the reservoir fluid. Thus, the calculation of dissolved geothermometer in the study area cannot be used to determine the temperature of the reservoir.

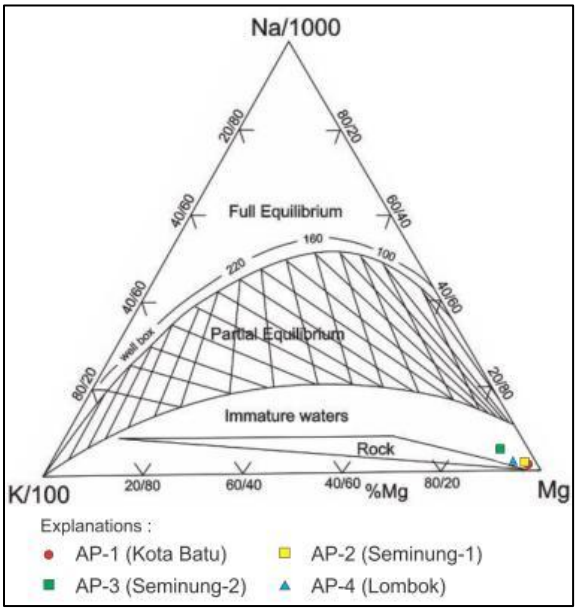


Figure 12: Triangle diagram of Na^{t}, K^{t}, and Mg^{2t} for the determination of reservoir temperature (Hastuti et.al., 2012, Unpublished).

CONCLUSION

Based on the lineament pattern data from the four lighting perspectives, it was found that the direction of the main trend from the area of Ranau Lake and it's surroundings is north-south (N-S). The direction of this lineament is interpreted as a secondary structure that results from the movement of the primary Sumatran Fault System structure that controls the entry path of the geothermal manifestation fluid. Based on the calculation of density values using the Fault and Fracture Density (FFD) analysis, the Ranau Lake is group into three density classes, namely low density (0-0.06 km/km²) which is shown in dark green-light green, medium density (0.06-0.13 km/km²) with yellow-young orange, and high density (0.13-0.19 km/km²) indicated by orange-red colour. Geothermal

manifestations are traversed by faults or fractures in regions with low to medium density values. Geothermal manifestations were found in the form of hot springs in four observation locations, namely Kota Batu (AP-1), Seminung 1 (AP-2), Seminung 2 (AP-3), and Lombok (AP-4). Geothermal manifestations are found in the form of hot springs with temperatures ranging from 43-57° C with a pH value of 4.8-7.1. Water geochemistry analysis showed that hot water source manifestations were found to be included in the type of bicarbonate water and the condition of the water was immature. This is indicated by the higher concentration of bicarbonate ions. Immature water conditions indicate that hot water has been diluted by surface water with a large concentration of magnesium in meteoric water compared to water originating from fluid flow with potassium content, so it cannot be used to determine the temperature of the reservoir. The petrography analysis found showed the presence of discontinuous minerals formed at high temperatures (plagioclase, pyroxene, biotite) and minerals that have undergone changes that are affected by hydrothermal solutions and control structures. Thus, the Ranau Lake area has the potential for geothermal exploration, but it is necessary to drill wells to determine the temperature of the reservoir in the area.

ACKNOWLEDGMENTS

The author would like to thank Dr. Ir. Endang Wiwik Dyah Hastuti, M.Sc. who have provided knowledge and guidance in writing this paper.

REFERENCES

Adama. (2017), "Analisis Densitas Kelurusan untuk Mengetahui Pola Struktur yang berkembang di Daerah Kebutuhduwur dan Sekitarnya Kecamatan Pagedongan, Kabupaten Banjarnegara, Provinsi Jawa Tengah", *Prosiding Seminar Nasional XII Rekayasa Industri dan Informasi 2017 Sekolah Tinggi Teknologi Nasional*, Yogyakarta

Cyrke A. N and Bujung. (2011), "Identifikasi Prospek Panas Bumi berdasarkan Fault and Fractue Density (FFD): Studi Kasus Gunung Patuha, Jawa Barat", *Jurnal Lingkungan dan Bencana Geologi*, Vol 2 no.1, April 2011.

Giggenbach, W.F. (1991), "Chemical Techniques in Geothermal Exploration. in: Application of Geochemistry in Geothermal Reservoir Development", *UNITAR/UNDP Centre on Small Energy Resources*, p. 119-144.

Giggenbach, W.F. (1988), "Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators", *Geochemical et Cosmochimica Acta*, Vol. 52, p. 2749-2765.

Hastuti, E. W. D., E. Sutriyono., B. K. Susilo. (2012), "Laporan Akhir Penelitian Strategis Nasional" *Universitas Sriwijaya*, Unpublished.

Kusuma, D. S., et all. (2005), "Prospek Panas Bumi Di Daerah Danau Ranau, Lampung Dan Sumatera Selatan". *Kolokium Hasil Lapangan*, 39-1 - 39-8.

Nicholson, K. (1993), "Geothermal Fluids Chemistry and Exploration Techniques", *Springer Verlag*, New York, p. 1-83

Nugroho, U, C. and Tjahningsih, A. (2016), "Lineament Density Information Extraction Using DEM SRTM Data to Predict The Mineral Potensial Zones", *International Journal of Remote Sensing and Earth Scienes, LAPAN* Vol.13, No.1, juni 2016, page 67-74

Pusat Survei Geologi. (2009), "WKP Panas Bumi Danau Ranau", *Pusat Survei Geologi (PSG)*, Bandung, p. 299-305

Suparno, S. (2009), "Energi Panas Bumi", *Departemen Fisikia-FMIPA Universitas Indonesia*

Thanoun, R.G. (2013). "Automatic Extraction and Geospatial Analysis of Lineaments and their Tectonic Significance in some areas of Northern Iraq using Remote Sensing Techniques and GIS", *International Journal Of Enhanced Research In Science Technology & Engineering Bulletin*, Vol. 2.