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Revisiting Galunggung Geothermal Field through geoscience perspective

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ABSTRACT

Galunggung volcano located on the southern side of Karaha-Bodas geothermal field also holds the potential for hosting geothermal prospect. Geoscience study has been previously carried out. Here, additional field observation was conducted which included geological observation and thermal manifestation. The still active Galunggung volcano potentially supplies the heat to the system according to the geology analysis and gravity data which needs to be confirmed by direct subsurface data. Only a small number of manifestations exist in this area. The situation differs significantly from the Karaha-Bodas field where the condition of manifestations is rather impressive. The manifestations are concentrated within the volcanic cone area, some are widely separated in the far southern area. The manifestations have quite distinct characteristics in both areas, where steam-heated springs with well-developed travertine deposits dominated the northern area manifestations, and peripheral chloride-bicarbonate springs with travertine deposits dominated the southern manifestations. The limited number of manifestations within the area makes it difficult to interpret the geohydrology and subsurface condition of the geothermal system. Additional extensive geophysics survey and analysis are needed up to the southern manifestation to accommodate unanswered questions of the extent of the system along with direct subsurface data afterward. The present study favors the possibility of clustered reservoirs existing in the geothermal area with the heat source situated in Mt. Galunggung and possibly near the southern area, and outflow represented by the thermal manifestation existence both in the north and south.

1. INTRODUCTION

Galunggung volcano located mainly in Tasikmalaya, West Java, holds the potential for hosting geothermal prospect. According to Van Bemmelen (1949), Galunggung area is physiographically situated in the boundary between Quaternary Volcanoes Zone (northern side) and South Mountain Zone (southern side). The volcano itself is of Quaternary age and is still active.

To the north of Mt. Galunggung, Karaha-Bodas geothermal prospect with its impressive geothermal signature is already in the exploitation stage. Meanwhile, no further exploration and development process has been made in Galunggung prospect up until the present time. However, Galunggung prospect is already included in the potential list of National Electricity Business Plan (RUPTL) 2021-2030 and could serve as additional capacity for electricity support considering there is at least 290 MW of additional energy needed from geothermal plants in Jawa-Bali area (PLN, 2021). Therefore, further study of this prospect is considered necessary, and any findings must be taken into account to understand the nature of the geothermal system in this area.

In this paper, a look back into the surface thermal manifestations in Galunggung prospect is done. Direct observation of the thermal manifestation was done to further confirm the manifestation observed in the previous study. Previous geochemistry studies from open-source materials will also be incorporated here to understand the geochemical process that occurred in this field. Additional lithology and geological structure studies were also done to comprehend the geological nature of the system.

2. PREVIOUS STUDY OF GALUNGGUNG GEOTHERMAL AREA

The geology of Galunggung volcano has been comprehensively explained in Bronto (1989) for both pre-1983 eruption and post-eruption. Though not specifically for geothermal exploration purposes, the study briefly mentioned the occurrence of thermal manifestation in the area.

Galunggung geothermal area has been previously explored by PT Energi Kinan Internasional (abbreviated into EKI for the next utterance) for preliminary survey according to the Decree of Minister of Energy and Mineral Resources No. 2491 K/30/MEM/2013 and currently is in Geothermal Working Area (GWA) tender stage. Through the survey, geoscience study comprised of surface geology, water geochemistry, soil geochemistry (Hg and CO_2), gravity, geomagnetic, and MT survey has been conducted. EKI highlighted the possibility of heat source/upflow coming from Mt. Galunggung or Mt. Kencana. Three separate clusters of reservoirs are identified in this conceptual model. The fluid is flowing to the south manifestation of Cigunung (ESDM, 2017). A similar interpretation is also expressed in Pratama, et al. (2015) where the latter modeled it into a 3D conceptual model. The conceptual model is presented in Figure 1.

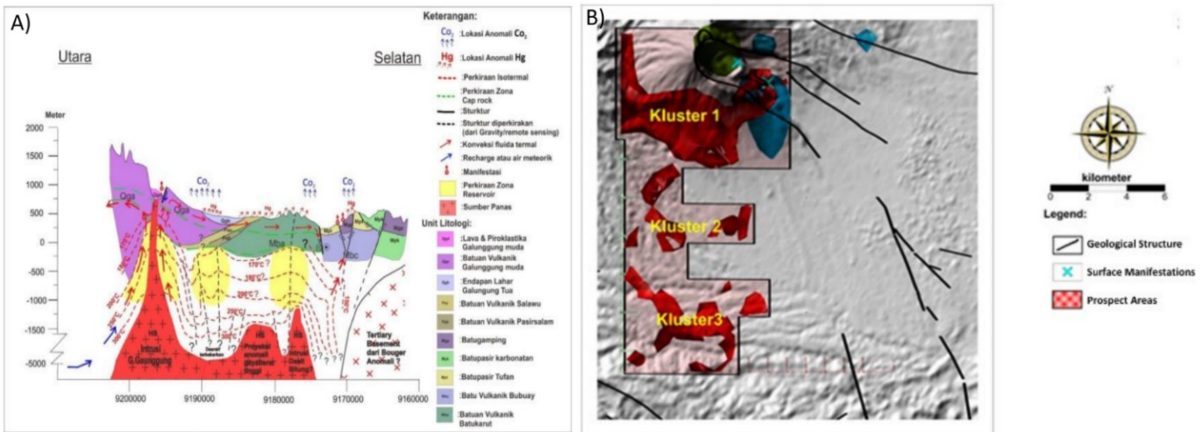


Figure 1: Conceptual model and resource area from PSPE study. A) Conceptual model in a cross section from north to south, showing three probable reservoir prospects (EKI, 2013 in ESDM, 2017). B) Three proposed prospect areas in map view (Pratama, et al., 2015).

In Prabowo (2020), geophysics study through gravity analysis resulted in the interpretation of heat sourced from the magma chamber of Mt. Galunggung and possibly connected to the heat source of Karaha-Bodas field in the north at about -3000 m depth (Figure 2). The subsurface geology interpretation in Figure 2 is very general because it only used the sampling density value of the closest field for reference, so the geology interpretation from EKI (2013) in ESDM (2017) is more considered. A normal fault is inferred in the summit area of Mt. Galunggung and possibly serves as a permeable pathway of manifestation. The study also mentioned the possibility of manifestation in the southeast to be the outflow of the system.

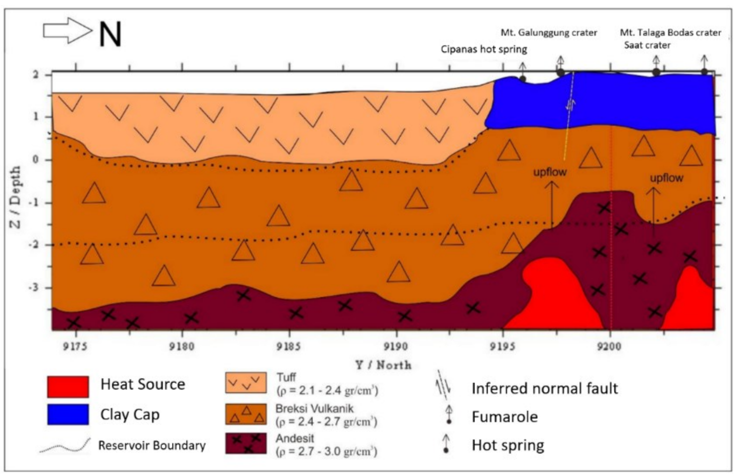


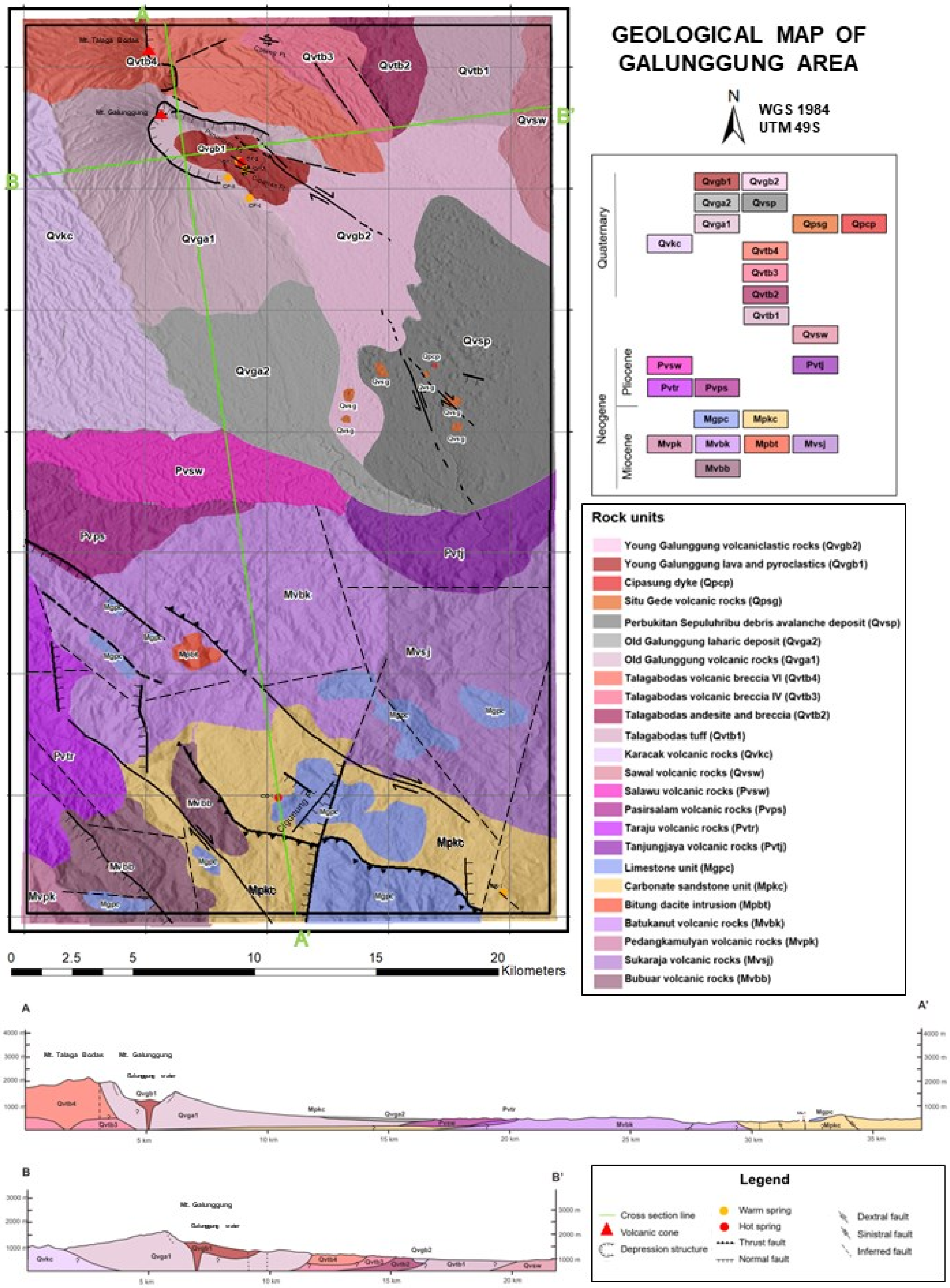
Figure 2: Geological model from gravity analysis in Prabowo (2020) showing a possibility of heat source connectivity between Galunggung area and Karaha-Bodas area at depth.

Up to the present time, no exploration drilling activity has been conducted in Galunggung area. The interpretation of geothermal resources in this area is only dependent on geoscience data previously surveyed by EKI. In this paper, no well data has been added to the interpretation of the geothermal resource, and the interpretation also highly relies on geoscience data.

3. GEOTHERMAL SYSTEM OF GALUNGGUNG AREA

3.1 Geology of Galunggung Geothermal Area

The Galunggung area is predominantly composed of volcanic products with some distribution of sedimentary lithologies. Using DEM and ridge alignment, also highly referencing geological survey results in Pratama (2015) and EKI (2013) in ESDM (2017), volcanostratigraphy analysis according to Marti, et al. (2018) was done to delineate the geology of the Galunggung area which results in a total of 24 units presented in Figure 3. The 24 units are Bubuar volcanic rocks (Mvbb), Sukaraja volcanic rocks (Mvsj), Pedangkamulyan volcanic rocks (Mvpk), Batukanut volcanic rocks (Mvbk), Bitung dacite intrusion (Mpbt), carbonate sandstone unit (Mpkc), limestone unit (Mgpc), Tanjungjaya volcanic rocks (Pvtj), Taraju volcanic rocks (Pvtr), Pasirsalam volcanic rocks (Pvps), Salawu volcanic rocks (Pvsw), Sawal volcanic rocks (Qvsw), Karacak volcanic rocks (Qvkc), Talagabodas tuff (Qvtb1), Talagabodas andesite and breccia (Qvtb2), Talagabodas volcanic breccia IV (Qvtb3), Talagabodas volcanic breccia VI (Qvtb4), old Galunggung volcanic rocks (Qvga1), old Galunggung laharic deposit (Qvga2), Perbukitan Sepuluhribu debris avalanche deposit (Qvsp), Situ Gede volcanic rocks (Qpsg), Cipasung dyke (Qpcp), young Galunggung lava and pyroclastics (Qvgb1), and young Galunggung volcaniclastic rocks (Qvgb2) from the oldest to the youngest.



(modified from Peta Geologi Lembar Tasikmalaya (Budhitrisna, 1986) and Geothermal Potential Book by ESDM (2017))

Figure 3: Geological map of Galunggung area modified from EKI (2013) in ESDM (2017). Some modifications that have been made include additional lineament analysis, confirmation of several faults through field survey, boundary of several geological unit, and cross section modification.

Lineament analysis was performed with context to the regional structural trends of the area. A high density of lineaments can be identified around the southern area where intense deformation seems to take place. It is hard to identify the lineament related to structural geology around Galunggung volcano as some lineaments are possibly related to lava ridge and younger deposits obscure the geologic structure traces. The contrast of lineament intensity coincides with the boundary between the two physiography zones previously mentioned. The lineament analysis, ground truthing, and literature study results are then incorporated into constructing a geological map in Figure 3. Both DEM-generated lineament and field measurements of structures display a similar trend of predominantly NW-SE pattern. Additionally, synthetic orientations of NNW-SSE and antithetic orientations, such as NE-SW, NNE-SSW, and N-S are also featured minorly in the lineament and structural data.

The reservoir of Galunggung prospect is predicted to be controlled by geological structure as well as lithological contact (EKI, 2013 in ESDM, 2017). Cipanas fault and Catang fault are two NW-SE oriented structures with oblique normal regimes according to field measurements. However, limited field measurements can be acquired in the field, thus a regional assessment was used as an approach to the regimes of fault orientations. The Meratus (NW-SE) and Indo-Australia (N-S) subduction events are the main tectonic events that form the regional structures in West Java. Fauzi, et al. (2015) identified surface compressional structures are mainly oriented NNE-SSW, while subsurface structures may vary between N-W, NE-SW, and N-S. A Riedel shear fault system model indicates the main NW-SE subsurface structure is the dextral primary deformation zone which induced the synthetic (R') NNW-SSE and antithetic (R') NNE-SSW structures on the surface (Figure 4). Therefore, NE-SW and NNE-SSW fault trends are more likely to provide secondary permeability.

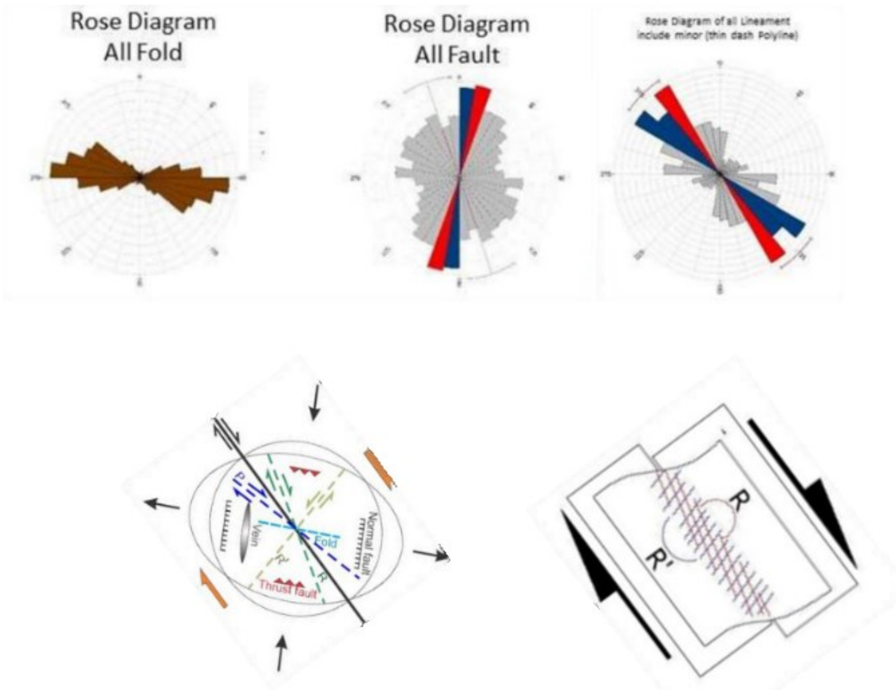


Figure 4: The rose diagram of surface-subsurface structures with a Riedel shear model that emphasizes the possible correlation between deep structures (NW-SE) with surface structure orientation that has NNE-SSW as the main orientation (modified from Fauzi et al., 2015).

The Galunggung volcano is located southeast of the Karaha-Bodas active geothermal field, evidence of the migration of volcanism from north to south. The Karaha-Bodas field also features similar structural trends of NW-SE and NNE-SSW, where NNE-SSW acting as permeability control as well as volcanic axis and intrusion pathway (Danakusumah & Suryantini, 2020). Whether the extent of the NNE-SSW reaches Galunggung further south is unclear as the recent deposit covers most of the surface outcropping of the structure. The interconnection between the hydrology is also unclear. However, the heat source of the two systems is expected to be interconnected based on high-density anomaly under the Galunggung crater and Karaha-Bodas system in the three-dimensional gravity inversion model section profile of the two (Prabowo, 2020).

3.2 Thermal Manifestation of Galunggung Geothermal Area

Previous studies have mentioned several hot springs and warm springs manifested in Galunggung area. Field-checking results on the spatial distribution of thermal manifestations are concordant with previous studies. In general, thermal manifestation in Galunggung area consists of hot springs and warm springs with the distribution centered within Mt. Galunggung volcanic cone (northern area) also Cigunung and Cibalong area (southern area). The distance between manifestation in the northern area and the southern area is considered to be pretty far where it can reach about 25-30 km. All manifestations have a neutral pH (6-7) with temperatures ranging from 32°C to 59°C (Table 1).

Table 1: Encountered manifestations in Galunggung area with its temperature, pH level, identified deposits, and surrounding lithology.

Location	Code	T (°C)	pH	Deposit	Surrounding lithology
Northern, Mt. Galunggung	CP-1	32	6	Travertine nearby	Andesite lava and lava breccia, pyroclastic deposit
	CP-2	59	6-7	Travertine along fluid path	Andesite lava and lava breccia, pyroclastic deposit
	CP-3	41	7	Travertine in fault plane	Andesite lava and lava breccia, pyroclastic deposit
	CP-4	50	7.5	Travertine terrace	Andesite lava and lava breccia, pyroclastic deposit
	CP-5	39	7.8	Travertine along the fluid path	Andesite lava and lava breccia, pyroclastic deposit
Southern, Cigunung	CG-1	55	7.5	Trace of travertine in the pool	Interbedded carbonate sandstone and siltstone with intercalation of limestone
Southeastern, Cibalong	CB-1	48	6	Travertine along the fluid path	Interbedded carbonate sandstone and siltstone with intercalation of limestone

Encountered manifestations in the northern area are mostly flowing through seepages of sloping land. The manifestations are situated inside Mt. Galunggung depression. The temperature varies from the lowest of 32°C to the highest of 59°C. Well-developed travertine deposits are spotted in several springs as shown in Figure 5. Travertine was also identified at several spots near CP-1 and CP-2 without any thermal spring spotted, indicating previous geothermal fluid activity nearby.

Figure 5: Several thermal springs in Mt. Galunggung (northern area). In CP-2, the travertine is formed along the main fluid pathway (A) and in the river lane (B). In CP-3 (C and D), fault with travertine deposit is identified. Terrace forming travertine is shown in E and F.

The thermal manifestation general distribution encountered at present is similar with the previous PSPE study, thus this paper will use previously conducted geochemistry analysis for subsurface study. According to the survey result of EKI in ESDM (2017) also Pratama, et al. (2015), thermal springs in northern area are categorized as neutral steam-heated water where the water is sourced mixing of condensed steam with meteoric water near surface. Travertine deposits developed around the manifestations show a strong influence of HCO_3 on the manifestation. Though having a higher ratio of SO_4/HCO_3 than southern manifestations, the northern manifestations might not directly indicate an upflow zone looking into the characteristic of the water (neutral pH, SO_4/Cl ratio is very high, no manifestations showing near boiling temperature). The upflow zone might be located in the crater area which is the closest to the eruption center of Mt. Galunggung, and where fumarole activity was previously reported in Bronto (1989). Additionally, isotope analysis ($\delta^{18}O$ and Deuterium) isotope analysis shows the fluid is derived from meteoric water without any mixing signature of magmatic input. Further, these manifestations are plotted as immature water, showing a high input of Mg. The fluid possibly comes from steam-heated groundwater or water from condensed steam mixed with groundwater.

The southern manifestations are categorized as peripheral water with higher Cl composition than northern manifestations, manifested as the result of lateral flow. The hot spring in Cigunung area has reached partial equilibrium state while the Cibalong spring is close to that state, indicating the possibility that the manifestation came from the reservoir and was diluted with meteoric water. Similar to the northern manifestation, travertine is also deposited around the manifestation as a sign of strong HCO_3 production from rock-water interaction.

The lack of thermal manifestation in Galunggung area is contrasted with the condition of its neighboring Karaha-Bodas field where the spatial distribution of thermal manifestations and its characteristics are quite impressive. Therefore, it is hard to determine the hydrology characteristics from geochemistry data and it needs to be assisted with other data, preferably direct subsurface data.

3.3 View on Geothermal System Condition in Galunggung Area

The geothermal system condition in Galunggung area remains ambiguous. It is hard to conclude whether the area from Mt. Galunggung to Cigunung and Cibalong belongs to one extensive geothermal system or not. As for its connectivity to Karaha-Bodas field, it is possible to say they come from a different system separated by the inferred structure in between both fields. Their heat sources are possibly connected at depth (Prabowo, 2020). The heat source in Galunggung prospect itself very likely comes from the Quaternary Mt. Galunggung indicated by steam-heated water of the northern manifestation although it does not really represent the upflow characteristics of a common geothermal system.

Previous studies mentioned the existence of three clustered reservoirs primarily through the interpretation of 2D MT data with the upflow located in Mt. Galunggung. The MT survey coverage however does not reach the southern manifestations area. Furthermore, the published result does not show the decency of the data, hence the hesitancy to rely on the MT data. Still, the published MT data is giving out the existence of conductive layer information which might indicate the existence of clay caps in this area. The hypothesis of clustered reservoirs is, however, reasonable considering the distance between one manifestation to others. The previous conceptual model mentioned the southern cluster to be the outflow of the system might correspond with the characteristics of thermal manifestations in the southern area which indicates an outflow characteristic. However, there is no geochemistry evidence of the northern and southern manifestations coming from the same reservoir. The Cl/B ratio shown in Pratama (2015) only indicates all manifestations in the northern area coming from the same source. Moreover, those manifestations do not exhibit acidic gaseous characteristics of the geothermal system upflow and might be considered to be manifested as nearby outflow as well. In the 3D gravity model of Prabowo (2020), a high-density body is identified in Mt. Galunggung and several high-density bodies are also identified in the surrounding area, including to the south of Mt. Galunggung. Though the model does not reach the southern manifestations, high-density body may be also present near the area, supplying the heat to the fluid which later manifested in Cigunung and Cibalong through faults. Moreover, intrusion activity is also identified about 7 km in the northwest of Cigunung manifestation, indicating the possibility of intrusion activity significant to the southern manifestations. This analysis is still very much speculative, but additional MT surveys within this area might help to answer the subsurface condition between northern manifestations and southern manifestations.

The previous study used Na-K geothermometer and it showed an overestimation value due to samples categorized as immature water. The northern manifestations do show immature water chemistry in Na-K-Mg analysis (see section 3.2), hence the use of southern partially equilibrated manifestations is preferred for geothermometer calculation. Additionally, the existence of travertine around the manifestations shows a high Ca^{2+} condition of the geothermal fluid under surface discharge conditions. This should be considered when estimating the reservoir temperature with a geothermometer to avoid falsely high-temperature estimation due to calcite precipitation affecting the calculation. The use of Na-K-Ca geothermometry method is preferred for this condition of the fluid with several factors to be considered. These new considerations to the manifestations and methods used for geothermometry calculations might yield different and more precise results to the real conditions of the reservoir.

4. CONCLUSION

At the moment, several preliminary geoscience studies have been conducted in Galunggung geothermal area. Surface geological study is looking robust already and needs to be confirmed with subsurface data. The lack of thermal manifestations within the area making it difficult to interpret the geohydrology and subsurface condition of the geothermal system. Although geophysics survey and analysis have been carried out, a more extensive additional survey is needed up to the southern manifestation to accommodate unanswered questions about the extent of the system. Direct subsurface data would also play a great part in assisting the interpretation if carried out. The present study favors the possibility of clustered reservoirs existing in the geothermal area with the heat source situated in Mt. Galunggung and possibly near the southern area, and outflow represented by the thermal manifestation existence both in the north and south.

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