The concept of geothermal exploration in west Java based on geophysical data

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Abstract. Indonesia has the largest geothermal prospects in the world and most of them are concentrated in Java and Sumatera. The ones on Sumatra island are generally controlled by Sumatra Fault, either the main fault or the second and the third order fault. Geothermal in Java is still influenced by the subduction of oceanic plates from the south of Java island that forms the southern mountains extending from West Java to East Java. From a geophysical point of view, there is still no clue or concept that accelerates the process of geothermal exploration. The concept is that geothermal is located around the volcano (referred to the volcano as a host) and around the fault (fault as a host). There is another method from remote sensing analysis that often shows circular feature. In a study conducted by LIPI, we proposed a new concept for geothermal exploration which is from gravity analysis using Bouguer anomaly data from Java Island, which also show circular feature. The feature is supposed to be an "ancient crater" or a hidden caldera. Therefore, with this hypothesis, LIPI Geophysics team will try to prove whether this symptom can help accelerate the process of geothermal exploration on the island of West Java. Geophysical methods might simplify the exploration of geothermal prospect in West Java. Around the small circular feature, there are some large geothermal prospect areas such as Guntur, Kamojang, Drajat, Papandayan, Karaha Bodas, Patuha. The concept proposed by our team will try be applied to explore geothermal in Java Island for future work.

1. Introduction

Indonesia has the largest geothermal prospect in the world [1]. It has many resources of geothermal energy derived from volcanic and non-volcanic rock in 285 Geothermal locations with a potential total output of 28 GW of electrical energy, one of the biggest in the world. The current installed capacity is 1,341 MW which puts Indonesia in the third position in the world after the USA (3,039 MW installed capacity) and the Philippines (1,904 MW). Therefore, more detailed research is required to develop the potential energy that can be used as an alternative energy besides oil and gas. Referring to the National Energy Road Map, the Indonesian government is targeting the use of geothermal energy that should be increased from 807 in 2005 MWe to 9,500 MWe by the year 2025. This is a part of new and renewable energy targets i.e. 25% of the energy mix by 2025. The development of geothermal projects in Indonesia has been a challenge. However, with the new Law on Geothermal Energy, it is estimated that the geothermal project progress will also be accelerated.

Indonesia's geothermal is concentrated in Java and Sumatera [2-4]. Geothermal on Sumatra island is generally controlled by Sumatra fault either the main fault or the second and the third order fault [5-8]. Geothermal in Java is still influenced by the subduction of oceanic plates from the south of Java island that forms the southern mountains extending from West Java to East Java. From a geophysical point of view, there is still no clue or concept that accelerates the process of geothermal exploration. The concept is that geothermal is located around the volcano (referred to the volcano as host) and around the fault
(fault as host) [9]. Another concept is from remote sensing analysis that often shows circular feature [10].

West Java has the largest potential area in Indonesia which is approximately 21.7% located in West Java, spread over 44 locations in 11 districts. Geothermal is a reliable energy for West Java. In 2004, the contribution of West Java geothermal energy to national need is of 749 MW from the total 807 MW (92.81%), coming from 4 PLTP namely Kamojang (140 MW), Awibengkok G. Salak (installed 6 x 55, raised 354MW), Darajat (145MW) and Wayang Windu (110MW) [11].

The problem with geothermal exploration was more on the time to search the prospect area than can take longer depending on manifested area from local people supported by Geological Survey, Geochemical Survey, Geophysical Survey to decide the regional area to become expected prospect area. It is expected that the concept of circular feature of low anomaly gravity will cut the series of geothermal exploration that should be done.

2. Geothermal Prospect Around Circular Feature of Low Gravity Anomaly

Relief-shaded Anomaly Bouger was created from Bouger anomaly data of Java Region so that the map has become three-dimension [12]. This shaded relief seen in low anomaly in central part of West Java shows a “circular feature” which is big enough to be categorized as the big circle, while the boundary of West Java and Central Java reflects a smaller “circular feature”. Viewed from the existing data, the geothermal prospect region is on the edge of the "circular feature” such as the prospect areas of Tangkuban Perahu, Ciater, Kamojang, Wayang Windu, Papandayan, Karaha Bodas, Cikuray, Guntur-Masigit, Patuha, Kawah Putih.

Likewise, smaller areas including Garut district and surrounding areas are seen in a small circle. In areas which contains a small "circular feature", we can find a similar "circular feature" where geothermal potential areas are located on the rim of "circular features", such as Kamojang geothermal, Darajat, Guntur-Masigit, Papandayan, Cikuray [13]

In West Java geothermal case, structures play an important role in localizing geothermal fluid circulation. Structures provide conduits for magma to ascend to the upper crust that may act as the heat source in geothermal system [14]. Structures also generate the secondary permeability where the heat transfer, hydrothermal fluids, and meteoric water interact and accumulate in a geothermal reservoir. Some of the structures will breach the system and will accommodate geothermal fluids to be exposed on the surface as geothermal manifestations. It can be generalized that the structures are involved in pre, sync and post genetic of the system. The explanation above also indicates that the control corresponds to different crustal levels. The role for localizing deep intrusions is controlled by deep seated structure, whereas localizing hydrothermal fluids is controlled by the thin skinned structure. Despite the importance of structure control, the geothermal system in West Java has never been associated with a major regional fault. In general, geothermal prospects in Java are highlighted to be associated with active arc volcano-magmatic [15, 16]. A close relationship of geothermal spatial distribution and regional-scale faults and lineaments has been noted [17], but the regional lineament was seen as a regional surface structure [13].

2.1. The Papandayan Geothermal

The main structure of the clay cap of hydrothermal system was found in the center of the model at 200 – 1000 m under the surface. This conductor ranging of 1-10 Ω.m formed an elliptic conductive cap with major axes of 2 km aligning in north-south direction. From the depth of 1000 m, there is a significantly resistive zone under the crater forming a conduit. The loss of high conductivity in this zone implies that the conductive clay cannot exist as the temperature is significantly higher than 200°C [18].

2.2. The Patuha geothermal

It contains the main lithological features, like the cap rock, the reservoir rock, the fault zones and the surrounding volcanic rock. Moreover, the most important surface manifestations are added to the model. The steady state temperature and saturation conditions are also included, as well as the temperature at
the surface and at the craters. It is basically assumed that below Kawah Putih there is a large heat source.
There is up-flow of heat through the fault zones and lateral flow at the depth of the reservoir rock. There
are also minor up-flow zones below the other surface manifestations. Nevertheless, based on the
chemical composition of the waters, the assumption is made that the Kawah Putih source is the most
important. The flow of fluid is mainly concentrated in the reservoir and the fault zones. The permeability
of these rocks is much lower than the surrounding volcanic rock and the cap rock.

The conceptual model of Eric Layman also assumes that the Patuha geothermal system is a vapor-
dominated system on top of a deep liquid zone. The size of the reservoir is approximately 20 square
kilometers. Besides these components, the centrally located magmatic plume is prominently present.
The presence of this plume is derived by the chemical composition of Kawah Putih. Layman does not
give any direct evidence of the presence of such a magmatic plume (there is no concrete data which
confirms the theory). However, similar features have been intercepted in similar systems (Karaha-
Telaga Bodas and Dieng) [19]. It was assumed that there is only a single heat source below Kawah
Putih. Moreover, the fumaroles in Kawah Ciwidey and Kawah Cibuni were supposed to be the result of
lateral flow from the central plume [20].

A magnetotelluric (MT) and time-domain electromagnetic (TDEM) survey are carried out in order
to obtain the resistivity values of the subsurface. Clay minerals are very good conductors due to their
internal structure, and therefore show a low resistivity. Clay minerals generally have a very low
permeability and can therefore be expected to act as cap rock. During this study, it is assumed that the
top of the conductor (based on resistivity values less than 10-15 ohm.m) is related to the top of the cap
rock. The cap rock appears closest to the surface at Kawah Putih. Clay minerals alter closer to the surface
due to higher temperatures near the up-flow zone. The pattern of low resistivity values appears to be
around Kawah Ciwidey and Kawah Cibuni. Combined with the data from the fluid chemistry of the two
Kawahs (craters), it could be possible that there are multiple up-flow zones appear in the system.
Temperature distribution Measurements of the temperatures of the fluids at the surface manifestations
show that at the Kawah Putih, Kawah Cibuni and Kawah Ciwidey the temperatures are the highest (>80 °C). Therefore, it is likely that the subsurface temperatures are also higher at these locations. At this
stage, these surface measurements are the only source of data for the temperature in the reservoir. The
occurrence of epidote, for example, is an indication for reservoir temperatures above 240 °C [20].

2.3. The Darajat Geothermal
The transformation of smectite to illite at shallow depths and the occurrence of amphibole in thin section
(both in disagreement with down hole temperature) reveal the presence of multiple geothermal events
in the history of the Darajat field associated with a heat source of more than 280° Celsius [21]. Integrated
geology, geochemistry and geophysics data show numerous similarities in the characteristics between
Darajat and the other known geothermal systems. Similar to the Geysers, the Darajat vapor system
evolved from a liquid dominated environment with a heat source of more than 280° Celsius and has
cooled off to the present temperature of 240° Celsius. Petrography work showed that alteration clays
and minerals deposited by the up flowing fluids from the past liquid system have significant control on
the plumbing and fluid paths of the vapor system [22].

2.4. The Tangkuban Perahu Geothermal
The calculated temperatures of thermal discharges of each neutral-pH water samples from Batugede,
Batukapur, Ciracas; Maribaya, and Cimanggu show the subsurface temperatures ranging from 121°C to
312°C. By using variation curve of Na/K ratio vs temperature, the underground temperature of hot
springs may be obtained. It shows various Na/K ratios from Ciracas, Batukapur and Maribaya hot
springs with temperatures ranging from 200°C to 285°C. These are assigned with high underground
water temperatures. The SiO2 and Na/K geothermometry of Tangkuban Parahu thermal discharges
represent subsurface temperatures ranging from 120°C to 310°C. The Ratu fumarole shows the existence
of SO2 and HCl gases which clearly represent high temperature volcanic gases, indicating that the
Tangkuban Parahu volcano is still active. According to the methane gas geothermometry and the
D’Amore and Panichi gas geothermometry, the subsurface temperatures of Ratu thermal discharge range from 280-400°C [23].

2.5. The Guntur Geothermal
The geothermal system beneath Guntur Volcano has existed but the system has not been developed perfectly. The cap rock was not detected by MT suggesting that the cap rock is not developed yet due to age of the volcano that is considered as young. The recharge area is predicted to be located around Putri Fault Zone, indicated by low resistivity zone in MT and shown as a bright line in ASTER-VNIR (Visible-Near-Infrared-Radiometer). The fault is detected deep enough to cut reservoir, about 500 m in depth. The discharge area is indicated by surface manifestations such as hot springs and fumaroles. The hot springs indicating the outflow zone probably appear from the fractures of Guntur-lava-unit, which is also a potential rock for reservoir. The occurrences of hot springs are also coexistent with high density fracture and fault map calculated from total lineament appeared in ASTER image. Fumarols occurred in the crater of the volcano mark the up-flow zone. This manifestation appears as bright tone zone in ASTER- TIR (Thermal-Infrared-Radiometer) image. The potential reservoir, Guntur-lava-unit, is associated with low resistivity of MT data. According to the previous tomographic study, the heat source of the system is probably the magma chamber beneath the crater, about 2-4 km deep below sea level [24].

2.6. The Kamojang Geothermal
Kamojang is the first Geothermal Field in Indonesia, and it is known as one of vapor dominated systems in the world. It first started producing steam in 1978 in order to generate electricity for its own use through a 250 KW monobloc unit. The first commercial operations of 30 MW started in 1982. Subsequently, an additional of 110 MW started commercially operations in 1987. Furthermore, a 60 MW unit is now under preparation to be constructed, and it is expected to be on line in 2006. In addition, the possibility of having another 60 MW unit is now being evaluated. The Kamojang geothermal reservoir is dominated by vapor with temperature of 235 - 245 °C and pressure of 34 - 35 bar abs. The potential resources calculated using volumetric analysis suggest a potential power of 150-250 MWe within the reservoir area of 7.52 km2 – 12.5 km2. Individual calculation had also been made. Fauzi, 1999, calculated proven reserve from reservoir area of 8.5 km2- 15 km2 and suggested a power of 140 MW to 360 MW for 25 years utilization. It has been estimated that proven reserves range from 210 to 280 MW for 30 years. The most likely potential power lies between 180 to 250 MWe for 25 years operation, which has been proven by drilling wells. To date, the field producing steam is equivalent to 140 MW electric [24].

2.7. Geothermal Field Classification in West Java
At least 62 geothermal fields to be potentially exploited are present on the island of Java [16]. The geothermal fields can be divided into volcano-hosted and fault-hosted geothermal systems based on their geologic association [26]. The former is a geothermal system related to a volcanic complex and the latter is a geothermal system located in a fault zone. Fault-hosted geothermal fields were not developed and are rarely explored, due to the assumption of insufficient energy. The volcanoes and faults on Java are host to at least 5 developed geothermal fields, most of which are located in the Quaternary volcanic arc, i.e. Darajat, Kamojang,Wayang-Windu, Patuha and Karaha-Bodas. As mentioned above, geothermal systems on Java are classified into volcano-hosted and fault-hosted. In West Jawa Area, from a total of 10 geothermal systems, 2 are considered fault-hosted (i.e., Ciarinem, Cilayu) and 8 are considered volcano-hosted (i.e., Tampomas, Tangkuban Perahu, Darajat, Kamojang, Wayang Windu, Patuha, Guntur and Karaha Bodas). All of the volcano-hosted geothermal systems are in the Quaternary volcanic belt, while most of the fault-hosted geothermal systems are in the Tertiary volcanic belt.

All of the geothermal systems might be associated with volcanic or non-volcanic. Volcanic geothermal system tends to show fumarole discharges on the surface, which indicates high temperature fluid within reservoir. On the contrary, non-volcanic geothermal system indicates low to moderate
temperature reservoir. The active manifestation of fumaroles and hot springs are distributed around craters as up-flow within Mt.Papandayan. The temperature of fumarole discharges ranging from 90°C to 260°C whereas the Ciarinem and Ciliayu neutral springs on the South and West flank indicate outflow zone. The CO2 geothermometer of fumaroles suggest that reservoir temperature equals about 310 °C [9]. The calculation of water geothermometer based on hot springs in North East flank of Mt. Tampomas is 180°C until 240°C. The geothermal system in this area is possibly associated with Mt. Tampomas potential heat source. The Papandayan prospect area is a prospect located in volcanic areas (Hochstein, 2015) whereas the Ciarinem and Ciliayu prospect ones are in fault areas [9].

3. Conclusions
From the Gravity Bouguer Anomaly of West Java, it seems that the Circular Feature low gravity anomaly is an "ancient crater". Ancient crater means that it is not always identical to the volcanic crater as it is today, but sometimes it is a hidden caldera. From the rim of the circular feature, there are some areas of high potential geothermal energy. In West Java area, there are some potential areas that come from small and big circular features i.e., Tampomas, Tangkuban Perahu, Darajat, Kamojang, Wayang Windu, Patuha, Guntur, Karaha Bodas, Papandayan, Ciliayu and Ciarinem. This circular feature of low anomaly Bouguer gravity could become the way on how to explore geothermal with geophysics methods, and it can be used to check another area in Java Island for future research.

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