Volcanological Approach for Evaluation of Geothermal Potential in Volcanic Associated Hydrothermal System at the Early Stage of Exploration

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ABSTRACT

Current exploration of volcanic-associated hydrothermal systems strongly relies on the occurrence of surface manifestations. In the absence or very limited occurrence of surface manifestations, evaluating the potential of a geothermal system is often doubtful. The absence or limited occurrence of surface manifestations does not mean that there is no geothermal potential in the prospect area. This is because the potential heat of a geothermal system is not only carried by the fluid that may appear as a surface manifestation, but also carried by the rock. If the rock that provides the source of heat exists, then the geothermal potential would probably occur in the area.

In some hidden volcanic hydrothermal system, the surface manifestation is limited or absent. However, if the age of the volcano is considered, it has high potential heat source since the age is very young, that is Quaternary to Recent. Thus, examination of the existence of young volcanoes is important for evaluation of potential heat source in the early stage of geothermal exploration.

This paper presents the role of volcanology when evaluating geothermal potential, in particular at the early stage exploration for delineating and promoting contract of work area. The paper discusses the application of this method with some examples from developed and undeveloped fields. The method is carried out by defining the volcanic edifices and their relative ages. Every volcanic edifice that has core volume greater than 50 km³ is considered as prospective. Later, the age or the last volcanic product is examined. The age between 50,000 to 250,000 years is preferred because the heat from magma chamber is still preserved. Lastly, the maturity of the volcanic eruption is examined. The volcano which resulted from the product of a single basaltic or ultra basaltic magmatic eruption is considered to be immature volcanic evolution. On the contrary, a volcano that erupted magmatic product from multiple basaltic or ultra basalt to andesitic and up to rhyolitic magmatic product is considered as mature volcano. By evaluating these criterias, the geothermal potential could be predicted. However, other components of a hydrothermal system still need further confirmation. A geochemistry and geophysics study must be conducted to confirm the existence of reservoir, permeability and other components. In summary, to some extent, application of volcanological approach in this early stage exploration for geothermal potential evaluation has provided more confidences in delineating the prospect area for proposing contract of work area.

1. INTRODUCTION

Exploration strategy for discovering volcanic associated hydrothermal system nowadays is strongly relied on finding the occurrences of surface manifestation as an indication of subsurface geothermal system. In the absence or very limited existence of surface manifestation, evaluating the potential of a geothermal system often gives doubts. This is because the absence or limited existence of surface manifestation does not mean there is no geothermal potential in the prospected area. The surface manifestation is the result of water and rock interaction during meteoric circulation or to some extent mixing with magmatic fluid circulation within the hot rock that contains heat. In the absence of this fluid, it does not mean the hot rock is also absent. Once the rock that provides the source of heat exists, then the geothermal potential must also exist in the area.

If the surface manifestation is limited or absent, the geothermal system is termed as hidden geothermal system. In geothermal system associated with volcanic heat source, it is called as a hidden volcanic hydrothermal system. In such kind of system, for example in geothermal system associated with young volcanic heat source, the occurrence of surface manifestation can be either limited or absent. On the contrary, if the age of the volcano is considered, young volcano which has Quaternary to Recent age is expected to contain significantly high heat which is potential for heat source in a geothermal system. Thus, apart from observing the existences of surface manifestation, examining the existence of young volcanoes is important for evaluation of potential heat source in the early stage of geothermal exploration.

This paper discusses the application of volcanology to evaluate the potential occurrence of geothermal energy in particular for a hidden geothermal prospect. This assessment is valuable to be conducted at the beginning of early stage exploration, in particular during area selection for further exploration program. The method for assessment is adopted from Wohletz and Heiken (1992). The study area is located in West Java, Indonesia.

2. EVALUATION OF THE GEOTHERMAL POTENTIAL OF COMPOSITE CONES

Composite cones, also called stratovolcanoes or stratocones, are large volcanoes that consist of multiple volcanic landforms such as interlayered pyroclastic rocks, lava flows, domes and volcanic sedimentics (Wohletz and Heiken, 1992). These authors developed a guideline to evaluate the geothermal potential of geologic settings with composite cones. The study for the guideline is based on the
assessment of geothermal power plants existing near these volcanoes, such as Momotombo, Ahuacapan, and the poorly-defined Kawah Kamojang Caldera. The summary of the guideline is presented in Figure 1.

Based on the guideline, the evaluation consists of five factors: (1) size and elevation of the cone complex, (2) degree of magma evolution from mafic to silicic compositions, (3) age of the volcano, (4) stress regime or distribution of the vents, (5) other factors such as the occurrence of surface manifestations.

The first factor is the evaluation of the size and elevation of the cone complex, which are used to infer the depth of magma intrusion beneath the cone. The shallower the magma intrusion level the higher the potential of heat released from the magma. The heat released is the potential heat source for the geothermal system. The size of the cone will help in delineating the lateral extent of the subsurface magma chamber that may control the lateral extent of the reservoir. It is expected that the larger the size and lateral extent, the larger the distribution of reservoir. A larger size can also imply that more heat is preserved within the magma.

During the early history of a magmatic system, many of the magma bodies are not able to reach the surface to erupt or even to be emplaced at shallow depths. Magmas lose heat through conduction to adjacent crustal rocks; they become highly viscous or more felsic in composition and their rise toward the surface is halted. It requires multiple periods of dike intrusion or the emplacement of diapirc magma bodies to create a zone or chain of heated pathways that enable succeeding magmas to reach the shallow crust. Such a heating process allows larger, more viscous, slower moving magmas to aggregate and form bodies that reach the surface or near surface and erupt. These shallower magma bodies associated with eruptions are ultimately the heat sources for geothermal systems. Larger and shallower magma intrusion is often associated with greater volcanic composite cone as the product of eruption. Thus the size or volume of composite cone can be used as indication to predict the size and depth of magma intrusion at depth.

The second factor is evaluation of the degree of magma evolution (Figure 2) from mafic to silicic compositions, which is used to infer how many succeeding magma intrusions had occurred beneath the composite cone. The more the succeeding magma intrusion occurs, the greater the heat from cooling magma is preserved. This heat is the potential heat source for the geothermal system. This assessment is based on the fact that during magma rise buoyantly to crustal depths, it changes in composition from more mafic to more silicic compositions. Compositional variations of magma are affected by the rate of plate movement, the angle of plate descent, irregularities in the descending plate, crustal thickness, and the depth and residence time of the magma reservoirs. For example, an intermediate or silicic magma body—either small or large—is to rise buoyantly to crustal depths; it must be heated from below by basaltic magmas from the asthenosphere. Without this thermal boost, silicic magma chambers cool and solidify; they may never reach the upper crust. Fractionation and mixing of basaltic and silicic melts can produce the spectrum of magma types and composition seen in composite cones. Therefore, knowing the composition of magma in composite cones is important to predict the amount of preserved heat content within the composite cone.

Magma composition can also be known from the type of the eruption product. Fissure vents magma discharge can form simple monogenic cone from mafic magma erupted during Strombolian or Vulcanian eruption with some thin lava flow. Fissure and central magma discharge can form multiple cones with intermediate to mafic magma composition due to Vulcanian eruption, lava flow and volcanic mudflow. Central and parasitic vents magma discharge can form multiple cones, domes, or calderas from intermediate to silicic magma erupted during Plinian and Pelean eruption. Other products such as pyroclastic flow and ash fall, lava
dome, and volcanic mudflow often occur during these last two types of eruptions. Surface manifestations are more intensive than two other previous magma discharges. The type or the magma discharges with its eruption product also suggest the maturity of magma evolution with the time. The more mature the magma evolution, the more silicic the magma gets and the eruption product contains more pyroclastic fall or flow rocks.

Figure 2. Evolution of magma and geothermal potential (Wohletz and Heiken, 1992).

The third factor is evaluation of the age of volcano or cone history that is to estimate whether the heat from magma emplaced at shallow level is still preserved and if the hydrothermal system has been well developed in the system. Many of the Earth's active composite cones are less than 200,000 years old. Some volcanoes have cone history for longer time and can reach 250,000 years old, but certainly less than one million years old. This age is mostly associated with mature composite cones, whereas immature composite cones can have histories shorter than 50,000 years.

The fourth factor is the evaluation of stress regime or distribution of vents, which is often indicated by the trend and orientation of mapped dykes. The symmetry of the dike complex may reflect fracturing and dike emplacement controlled by stress around the central pluton (or plutons) or tectonic control. These dikes would have provided a substantial heat source if they were intruded over a fairly short period of time, but not if they were intruded piecemeal over tens of thousands of years. Such dikes also can act as barriers to groundwater flow and thus can "compartmentalize" aquifers or parts of a hydrothermal system. In addition, parallel dike systems support only the part of the volcano below a line of parasitic vents; unsupported flanks, with only rare dikes or sills, are subject to sector collapse.

And the last factor is an additional factor that encourages the hypothesis of the existence and location of a hydrothermal system such as occurrence of an active surface manifestation. The more intensive the surface manifestation, the more confident the prediction of hydrothermal existence nearby the location.

3. EVALUATION OF THE GEOTHERMAL POTENTIAL AT THE CIPANAS GEOTHERMAL PROSPECT, TASIKMALAYA, WEST JAVA, INDONESIA

The Cipanas Geothermal Prospect is situated at the southern flank of the Galunggung Volcano. This volcano is located at the southernmost part of the Karaha-Telaga Bodas-Galunggung Volcanic Complex (Figure 3). Drilling has proved that the Karaha-Telaga Bodas Volcano has some geothermal potential. The Galunggung Volcano’s last eruption was in 1982–1983. The volcano rises from nearly 500 m a.s.l. up to more than 2,200 m a.s.l. If the distribution of 500 m contour line is taken as the base of the volcanic cone and the highest elevation is assumed to be 2,200 m, the calculated cone size gives a volume of greater than 60 km³.

A study to investigate the products of Galunggung’s last eruption was conducted by Bronto (1989). The study suggested that the low-K, high-Mg basalts are the predominant volcanic products of Galunggung. The magma has evolved at least from about 50,000 (?) years ago until the eruption in 1982–1983, initially producing low-Mg basaltic andesites followed by high-Mg basaltic andesites, "transitional" high-Mg basalts, and finally high-Mg basalts. Pumice clasts of rhyolite composition observed in the last eruption may have been derived from re-melting of the Miocene dacite. This study serves as a foundation for the interpretation that Galunggung has a mature magma evolution. Additional data to strengthen this hypothesis is that the center of eruption of the Galunggung-Karaha-Telaga Bodas Volcanic Complex has evolved to central and parasitic vent, not to fissure vents anymore and produced multiple cones, domes, and calderas from Plinian eruption that deposited pyroclastic flows, ash falls, and volcanic mud flows. These characteristics fit the criteria suggested by Wohletz and Heiken (1992) as shown in Figure 2.

According to Bronto (1989), the age of Galunggung since its early development is at least 5,000 years. The latest eruption suggests that magma has been renewed by new intrusion. Thus, it is expected that the heat is preserved within the magma.

Although Bronto (1989) did not carry out dike mapping in this area, he mentioned that several dikes can be observed within the Galunggung caldera wall. Some dikes occur in the SE and NW caldera walls. The cross section and photograph by this author depicts that the dike orientation is more or less radial from the crater. Dikes were not observed outside the caldera wall. This radial
trend of dike suggests that the Galunggung Volcano is the central eruption. Thus, the highest potential heat source of this prospect pointed the Galunggung Volcano and the surrounding area.

Figure 3. Topography of the Galunggung-Talaga Badas-Karaha Volcanic Complex, surface manifestation of the Cipanas Prospect and proposed contract of work area.

There is very limited or almost no surface manifestation in the Galunggung Crater. Besides the crater morphology, no other active manifestation can be found in this crater except some small bubbling cold springs around the cold neutral crater lake. A touristic area called Cipanas is located about 500 m down slope of the crater. This area is the only location where surface manifestation can be clearly observed. The manifestation consists of several springs and seepage of thermal water that emerge from the contact between the pyroclastic flow breccias and older deposits along the Cipanas River. It discharges to the Cipanas River and the temperature of the river increases up to 60°C. This is where the name of the river comes from; “panas” means hot in Indonesian language. The manifestation is shown in Figures 4 and 5. Some alteration (iron oxide and locally silica) occurs at the location where seepage emerges.

Based on the above evaluation following the guideline of Wohletz and Heiken (1992), most criteria to have a possible geothermal occurrence in this prospect are satisfied. It can be suggested that the prospect has some geothermal potential with possible high potential geothermal energy. However, further detailed surveys must be conducted to confirm this preliminary interpretation.

There are two warm springs located about 25 km south of the Galunggung Volcano, namely Cigunung and Cibalong. These two warm springs are suggested to be the outflow of the Cipanas system. However, in terms of physical volcanology and geomorphology, these springs are located far outside of the Galunggung Volcano cone. Both springs are situated in the Tertiary deposit, and thus, it is suspected that they are not associated with the Cipanas Prospect, where Galunggung is the potential heat source. This is confirmed by the conservative elements from both springs, which differ from the conservative elements of the Cipanas stream. Thus, the two springs are not necessary to be included within this area (Figure 3) in case of a proposal for contract of works.

4. DISCUSSION ON THE GEOTHERMAL POTENTIAL OF CIPANAS GEOTHERMAL SYSTEM, TASIKMALAYA REGENCY

The Cipanas Geothermal System in Tasikmalaya Regency can be classified as a hidden volcanic-associated geothermal (hydrothermal) system, because of the limited active manifestation in the prospect area. As a result, exploration in this prospect is difficult and risky, and as such, these prospects are often avoided by the geothermal industry.
The volcanological approach used in this study has proved that this prospect has a high geothermal energy potential. However, a detailed survey is required to better confirm this preliminary prediction. Further exploration surveys, such as geophysical surveys using MT or other resistivity/EM methods, are suggested for this hidden geothermal system to locate the reservoir. Gravity and geomagnetic surveys are needed to locate the possible location of the older structure underlying the cone. Geophysical survey design must consider the subsurface geology (such as the distribution of volcanic deposit and structural geology) and, to a small extent, the geochemical information, sample locations in the groundwater well, soil sampling or soil air sampling. In general, geochemistry and geophysical studies must be conducted to confirm the existence of a reservoir, and to get the information of its permeability and other components.

The volcanological approach discussed in this study helps to increase the confidence level of the occurrence of the geothermal system in a hidden geothermal prospect, as shown by the Cipanas example. It is expected that in every hidden geothermal prospect, particularly in composite volcanoes, the exploration program will begin with such studies before carrying out more detailed and expensive exploration programs.

In summary, application of a volcanological approach in this early stage exploration for geothermal potential evaluation has provided more confidence in delineating the prospect area for proposing contract for the study area.

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REFERENCES


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