Volcanostratigraphic Approach and its Implication for Geothermal Evaluation in Talang Volcano West Sumatra

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Abstract. The desk studies are a fundamental preliminary step in any geologic investigation of volcanic regions. These studies are very important approaches used in the reconnaissance survey stage for the exploration of volcanic geothermal systems. Volcanostratigraphic study has been done in Talang volcano and nearby regions, where the two topographic maps on the scale of 1:100000 and 1:50000 were utilized by drawing the patterns of drainage, ridges and flows without intersecting these flows. The first scale employed to distinguish eruption product units based on their respective eruptive centers (Crown), as well as a map on 1:50000 scale to find detailed parasitic distributed unit(s) product such as (Hummock). The challenge based on this approach is to distinguish different volcanic products based on their origins without ground truthing. Thus, the correlation with existing published geological map was employed. One volcanic unit were identified (Talang Brigade) which consists of three eruption centers (The Talang Bawah, Talang Batino and Talang Jantan Crowns) and three Hummocks with different ages based on age of eruption. The volcanostratigraphic units, is bounded by a large Talang Brigade caldera with a diameter more than 2 km. Based on analyses of the dimension, maturity, stress regimes, and an estimation of the thermal resource base of its magmatic heat source, it was concluded that Talang volcano as a geothermal potential that deserves further detailed studies before embarking to development phase. For verifying desk work studies, the detailed volcanostratigraphic mapping is recommended to understand the physical- and chemical properties of the volcanic rocks and provide the history of volcanism and validation of the potentially geothermal boundaries.

1. Introduction

Volcanostratigraphy is one of the geological disciplines relating to volcanism and its products, to understand the volcanic history and characteristics of the volcanic deposits or rocks [1]. This study deals with the spatial and temporal arrangement, relationship and origin of volcanic strata, volcanic rocks and its deposit in an area. In geothermal exploration, especially in Indonesia, volcanostratigraphic studies are very important in delineating and estimate the volume of magma chamber, defining the reservoir rock host the fluids as well as distance estimations from the center of the volcano [2]. Indonesia has more than 130 active and non-active volcanoes that are mostly distributed along the active subduction zones of the islands of Sumatra, Java, Bali, Flores, North Sulawesi, and Maluku archipelago. This
approach has been consequential in these provinces. Many geothermal prospects around these regions have been proven to host high temperature geothermal systems (>225°C) [3].

In preliminary exploration stages of volcanic geothermal systems, geological mapping is employed as a standard practice [4]. However, this mapping practice by using contour map and correlation with the existing geological map is not of much significant. Hence the main challenge that may arise is the difficulty in delineating different existing eruption products and its distributions without directly visit the study area. The problem becomes even more pronounced in composite volcanic complex and old calderas. In the case of stratovolcanoes such as Talang volcano, the difficulty is due to the different eruption cycles, which yield eruption products (pyroclastic rocks and lavas) that are nearly similar in both their physical appearance and characteristics, while in older calderas and volcanoes the challenge is because of the combination of both the former effect and the complex morphological features due to advanced erosion stage [2].

Before commencing the detailed geological exploration, it is advised to perform volcanostratigraphic studies. This paper describes the volcanostratigraphic geothermal potential analysis based on the topographic maps of the Talang volcanic region at a scale of 1:100000 then detailed smaller scale of 1:50000. Talang volcano with an elevation approximately (2,597 m) is an active stratovolcano (last eruption dated on December 2007) in West Sumatra, Indonesia. Talang has two crater lakes on its flanks, the largest of which is 1 x 2 km wide and is called Lake Talang [5]. Topographic map analysis involves the classification of volcanostratigraphic units, namely Crown, Hummock, Brigade, Super Brigade and Arc [6] based on the identification of source of eruption, analysis of ridge lineament and drainage flow pattern, and volcanic units and/or facies boundaries. Volcanostratigraphic interpretation is then conducted by correlation between the result of topographic map analysis and a published or existing geological map. Regarding to these approaches the volcanostratigraphic analysis of Talang Volcano prospect is established which is not yet fully described on local map scale.

2. Geological Setting
Geologically the area is covered by Tertiary – Quaternary ages of rocks that are composed of Metamorphic rocks, Trts (phyllites), Old volcanics, QTau, (andesites, tuff breccias), lava volcanics, QLv (andesites, tuff breccias, pyroclastics) and surface deposits, QLh [7, 8] (Figure 1). Generally, metamorphic and volcanic rocks are weathered, in some places the volcanic rocks are also altered, and characterized by sericite and chlorite. In addition, on volcanic rocks the columnar and sheet joints occur which is an indication of good porosity and permeability. Therefore, this is a media for transferring surface water into a geothermal system in the area. Faults and volcanic rings (result of volcanic eruption) are common in the area. The faults are normal and trending NW-SE, N-S and NE-SW. Among the faults Batubajanjang fault is important as its control the geothermal manifestation in Talang Mountain as the surface discharge [9].

3. Methodology
Volcanostratigraphic unit classification begins with the identification of the local highest peaks around Talang Volcano These peaks are symbolized with red triangles. The second step consists of identifying circular structures, which are mostly characterized by closures that are expressed by the highest elevation contour lines. These structures represent concentric depressions. The presence of both the highest peaks and circular depressions mark the existence of the post eruption centers. These centers could be used as a guide for predicting the distribution of each of their respective eruption products. The third step was to trace every single drainage pattern (rivers) by using blue color to mark their flow patterns. At the same time, patterns which represent ridges were also traced and marked with brown color. These ridges generally lie between two rivers and/or at the edges of circular depressions. In general, the distribution of rivers and ridges around an eruption center will form a radial pattern, even when the volcano has experienced advanced erosion stage [10]. The presence of different volcanic units can be identified using the distribution of those patterns, and the boundaries of individual units were then marked with dashed lines. The geothermal potential evaluation of Talang Volcano was done by
adopting and suggesting the new scheme proposed [2]. The scheme employs a flowchart with a series of geological and physical parameters as the constraints for decision-making (Figure 2). For the case of Talang Volcano a simplifying assumption is that, the area is a complex composite shape with caldera-shaped and younger dome was emplaced such that its magma chamber volume can be estimated and locating the zone of permeability.

![Geological Map of Talang Volcano](image)

**Figure 1.** Geological map of Talang volcano modified from [7, 8]

The degree of magmatic evolution was estimated using the variety of volcanic and intrusive rock types around the volcano, all of which are listed in the original published geological map, whereas the degree of volcano’s maturity was estimated by comparing the volcanic parameters of Talang Volcano to those listed in (Table 1 and Figure 3). The assumption that Talang Volcano volcanic complex are entirely comprised of layers of volcanic products with equal proportions (50% pyroclastics and 50% lavas), and that the eruptive volume represents about 10% of the total magma chamber volume [2, 11], the resource base estimation of magmatic thermal energy contained within Talang Volcano magma chamber volume could be calculated by the following procedures:

\[
V_{\text{volcano}} = \frac{1}{3}\pi r_{\text{top}}^2 \times h_{\text{simple}}
\]

Where, \(V_{\text{volcano}}\) is volume of volcano in (m³)

\(r_{\text{top}}\) is the minimum crater radius of the crater (m)
Evaluation of volcano’s size is used to estimate the depth of a magma intrusion beneath the surface. The shallower magma intrusion, the greater potential into heat source of the geothermal system. The size of the volcano will help delineate the area of magma chamber that lies beneath the surface. Such area may be associated with an area of reservoir. Degree of volcano’s maturity was estimated by comparing the volcanic parameters which is listed in (Figure 3). Based on the available literatures the composition of magma could be known and can estimate the heat which is contained in volcano. Composition of magma changes from mafic to silicic along with rising magma to the surface. Shallow magma confined close to the subsurface causes’ assimilation with the surrounding rocks which increase silica content. Besides, several intrusions cause mixing between shallow magma and deep magma which can move upward to the surface. The composition of magma can also be expected from the type of volcanic eruption. Strombolian and Vulcanian are types of eruption that can produce monogenetic cones of mafic magma. Central vent and fissure vent can produce complex cone of mafic-intermediate magma from vulcanian eruption type.

While the central vent can produce complex parasitic cone, dome and caldera of intermediate-silicic magma which type of eruption is Plinian or Pelean. When basaltic magma from crust flows up to the surface caused by fracture or fissure its composition will get changed through magmatic differentiation, mixing or assimilation. If fractures or fissures that act as magma discharge path are small, it will prevent magma to emanate to the surface so that its composition will get changed into intermediate or maybe silicic while prevented in subsurface. The more the process of mixing or differentiation that occurs the composition of magma will increasingly intermediate or silicic when emanates to the surface. Figure 3 shows that maturity degree of volcanoes can be characterized by its products that are pyroclastic flows and ash falls.

**Table 1. Eruption styles and maturation contents of the Talang Volcano.**

| Eruption Type | Morphology of Mountain | Type of Magma       | Maturation          |
|---------------|------------------------|---------------------|---------------------|
| Plinian       | Caldera and Dome within the center | Intermediate to Silicic | Older (Mature)     |
| Pelean        | Dome                   | Silicic             | Older               |
Figure 2. The evaluation guideline for geothermal potential in Talang stratovolcano - modified from [2]
4. Result and Discussion
The results interpreted from topographic map were then compared with published geological map of Mount Talang with the nearby provinces (Figure 1) and there is relatively good correlation between the interpreted volcanostratigraphic unit boundaries and the distribution of volcanic lithological units. It also implies that there is a correlation between the distributions of eruption products and the morphology of volcano. Based on the interpretation of Talang topographic map at a scale of 1:100000 (Figure 4) the units that were identified are Talang Brigade with three Talang crowns, namely Talang Bawah Crown, Talang Batino Crown and Talang Jantan Crown (Figure 6a and 6b).

A detailed topographic map on scale of 1:50,000 (Figure 5) and satellite images was also analyzed for three crowns identified around the southwestern part of Talang. There are 3 additional Hummocks surrounded by a huge caldera which could be the boundary of the Talang geothermal system (Figure 6). It was investigated that each Talang Crown contains its monogenetic (parasitic) volcano which could be emplaced during different geological time scales. The Talang Bawah, Talang Batino and Talang Jantan Crowns composed with Bakar Hummock, Batino Hummock and Jantan Hummock respectively on a
map scale of 1:50,000. The Batino Hummocky is older while the Jantan Hummock is the youngest as shown in (Figure 6a).

For the analysis of Talang Volcano dimension, the diameter is taken as the average distances between pairs of slopes with the lowest inclination of 3 km radius [12]. And an elevation difference of 3.6 km obtained, and therefore a volume of 33.912 km$^3$ when calculated using equation (1). This is certainly an overestimate, since all the parameters and assumptions used were derived only from the morphology of the volcano as well as the results obtained from previous studies. In addition, it is also necessary to understand that the model for calculation did not consider the effect of magmatic recharge into the volcano’s magma chamber prior to past eruption cycles. In development based on degree of magmatic evaluation, the basaltic-andesitic magma is rarely tapped for geothermal power. So, the system also is low because it is reach with the basaltic-andesitic magma. This reflection also is portrayed on the age of volcano which is less than 50,000 years old also the development of this system is low.

The overall stress regime of Talang volcanic edifice is interpreted to be homogeneous, as indicated by the dominant orientation of faults crossing the volcanic edifice (NE-SW and NW-SE) as well as the radial arrangement of rivers and ridges that are centered towards the volcanic vents towards outward flows. Although the volcanic rocks of Talang Volcano, being andesitic, suggest that the volcano has experienced a low degree of magmatic evolution, the volcano itself can be categorized as in a sub mature-mature stage when we take the vent distribution and the general shape of volcanic edifice into our consideration using (Figure 3).

![Figure 4. The peak, ridge and river patterns based on morphological analysis using the scale 1:100000 topographic map of West Sumatra region.](image-url)
Figure 5. The peak, ridge and river patterns based on morphological analysis using the scale 1:50000 topographic map of Talang region.
Figure 6. (a) Distribution of Talang Brigade that composed of Talang Bawah Crown, Talang Jantan Crown and Talang Batino Crown on the map scale 1:50000 with Hummocks and (b) Volcanostratigraphic unit distributions on 1:100000 scale respectively.

5. Conclusion
The study area is grouped into Talang Brigade that consists of Talang Bawah Crown, Talang Jantan Crown and Talang Batino Crown. Each Crown has a hummock, i.e. the Talang Bawah, Talang Batino and Talang Jantan Crowns composed with Bakar Hummock, Batino Hummock and Jantan Hummock respectively on a map scale of 1:50,000. This interpretation can be used as a first consideration before executing a detailed geological field mapping, as the campaign can now be focused on the bigger area, main eruption vents such as Talang Crowns since they can be used to indicate the presence and relative position of the main magmatic heat.

Following the potential before development the parameters such as dimension, age, and stress regime all make it possible for a geothermal exploration and development program to be conducted in Talang stratovolcano. However, the lower degree of magmatic evolution suggests that there is a low possibility for such program. Nonetheless, the estimated amount of magma chamber volume, together with the fact that this volcano is a mature stage further detailed exploration studies need to be undertaken in Talang Volcano geothermal prospect.

Acknowledgement
We would like to thank Dr. Eng. Suryantini, Prof. Sutikno Bronto and Dr. Yustinus Suyatno Yuwono for their knowledge sharing and guidance which made us to finalizing this work.
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