Preliminary study of Songa-Wayaua geothermal prospect area using volcanostratigraphy and remote sensing analysis

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Abstract. Songa-Wayaua geothermal prospect area is located on Bacan Island, Northern Molluca Province. Geothermal systems in this area associated with three Quartenary volcanoes, such as Mt. Pele-pele, Mt. Lansa, and Mt. Bibinoi. Based on literature study, five surface manifestations such as hot springs and alteration occurred within this area. The active manifestations indicate that Songa-Wayaua area has potential geothermal resource. This study objective is to evaluate Songa-Wayaua geothermal system on preliminary study stage by using volcanostratigraphy and remote sensing analysis to delineate the boundary of geothermal system area. The result of this study showed that Songa-Wayaua prospect area has four heat sources potential (e.g. Pele-pele Hummock, Lansa Hummock, Songa Hummock, and Bibinoi Hummock), controlled by geological structure presented by Pele-pele Normal Fault, and had three places as the recharge and discharge area which are very fulfilling as a geothermal system.

1. Introduction

The tectonic position of Indonesia which is on the Ring of Fire resulting a big potential of geothermal resources. This renewable energy is expected to replace the fossil energy later. Geothermal energy development on the eastern part of Indonesia is less developed than on the western part of Indonesia, whereas eastern part of Indonesia is still lack of electricity. Thus, it needs more geology explorations in order to find new potential area of geothermal resources. Determination of an area that has geothermal prospect usually depends on the geothermal surface manifestations. However, the occurrence of these geothermal manifestations is very limited and sometimes absent, so it can be obstructed in determining the geothermal system, especially in volcanic regions and green field area.

The preliminary studies which can be used before the field survey are volcanology study and remote sensing analysis [1]. Volcanostratigraphy study aims to classify the eruption products based on source. The classification based on the eruption center is important to localize the areas that most likely located near a heat source or associated with the magmatic intrusions that are still active or dormant. Then, remote sensing analysis aims to find thermal anomalies on the research area so we can obtain the conceptual model of permeable zone beneath the research area, also the lineaments study so knowing the trend and stress regime which developed at the research area [2, 3]. Furthermore, the
study objective is going to identify each components of geothermal system in Songa-Wayaaua prospect area (figure 1).

Songa-Wayaaua is located on the eastern part in Indonesia, which needs more electricity, and has a prospect of geothermal potential. Tectonically, Songa Wayaua is very complex and the chemistry of the volcanic rocks different with Halmahera region [4]. Most of the basement rock formation of Songa Wayaua is from continental crust (Australia plate), while the volcanic rocks of Songa Wayaua was the result of magmatism related to movements along the sinistral Sorong fault [5].

![Figure 1. The research area at Songa Wayuuaua, Bacan Island, South Halmahera Regency, North Mollucas Province, presented by red rectangle.](image)

2. Methods

2.1. Volcanostratigraphy Analysis

The basic method of geological mapping in volcanic region is volcanostratigraphy. This method is used because the volcanic facies rapidly changes both lateral and vertical succession. The volcanostratigraphy unit which similar to Formation is Crown, while smaller unit is called Hummock. The group consist of two or more Crowns are called Brigade, and Brigade series compose an Arc [6].

The initial stage of volcanostratigraphy unit determination is delineating non-volcanic rocks to define the base of volcano in research area, so that we become more focused on volcanic rocks mapping.

The first step is overlaying the same scale of topographic maps with the regional geological map. The next step is identifying of volcanostratigraphy unit using the topographic maps (scale 1:100,000). Volcanostratigraphy units are determined based on the eruption centre, ridge lineaments, stream or drainage system, and also base of volcano boundaries.
The stage of volcanostratigraphy unit analysis begins with local highest peaks identification which commonly symbolized by the triangle symbols on the maps and with specific elevation. Furthermore, identification of circular features that is generally characterized by circular pattern elevation contours with concentric pattern elevation contours in the middle. These structures characterize the existence of circular depression, caldera, or crater as the central of major eruption.

In this research, volcanostratigraphy analysis was based on topographic maps: Silang sheet [7] scale 1:100,000, North Mollucas, which next is compared with geological map: Bacan sheet [8]. The research area administratively is located on Songa Village and Wayaua Village, East Bacan District, South Halmahera Regency, North Mollucas. Based on regional geological maps, the research area consists of three major lithologies [9], i.e. Holocene Volcanic Rocks and Bacan Formation, composed by volcanic rocks, on the centre and eastern part of research area, and Sibela Metamorphic Complex, on the western part of the research area as basement rocks.

Generally, ridges and streams surrounding the central eruption forms radial drainage system, even when the volcano has undergone advance erosion [10]. The assumption was used to withdraw base of volcano border is when the ridges and the drainage systems form concentric radial pattern, then it is considered has same source [11]. Crown unit is characterized by concentric contour pattern of a big size volcano cone or group of volcano cones that are related genetically, while hummock unit is characterized by the small volcano cone contour pattern around the crown. Each crown or hummock that had been identified subsequently named according to its local geography.

### 2.2. Remote Sensing Analysis

Remote sensing is one of typical study to identify the geological structures by observing the lineaments. The identification of lineaments could be done by using topography maps and available remote sensing data [12]. The lineaments can be formed by the erosional process on the ridge pattern, specific topography forms, and drainage system. In this research, the lineaments were indentified using synthetic aperture radar (SAR) image using Sentinel 1-A satellite: dual orbits, consists of ascending and descending with single polarization.

Ascending and descending images can be distinguished by the acquisition process. Ascending images were acquired from west to east side-looking with the satellite led from the south to north, while the descending image were acquired from east to west side-looking and satellite led from north to south. This acquisition would display different results, so the combination of both lineaments of these images will obtain a comprehensive lineament patterns.

All lineament patterns anaysis might indicate that the research area has faults and fractures as geothermal permeable zone. To support the classification based on the area, we calculate the quantity and the length of each lineament which overlay on 1x1 km grid. The lineaments length of each grid was mapped. This analysis was known as Fault Fracture Density (FFD) Analysis [13].

The area of geothermal system is usually characterized by manifestations with high temperature relatively, resulting plants or vegetation on the surface become damaged, usually called vegetation stress [5]. We also do NDVI analysis to detect the appearance of vegetation stress from remote sensing by calculating the surface reflectance values using Normalize Different Vegetation Index (NDVI) formula (equation 1). The calculation of NDVI index is using satellite imagery that has visible red and near infrared band.

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NDVI = \frac{(Near\;Infrared - Visible\;Red)}{(Near\;Infrared + Visible\;Red)} \tag{1}
\]

Index of NDVI calculation will show the distribution of vegetation stress or healthy vegetation location [14]. However, it may need further analysis, because small NDVI index also may show there is no vegetation on the location for the residential or manmade, and also the presence of cloud covering the research area.
3. Results

3.1. Volcanostratigraphy Study Result

Based on the analysis of pattern and population of ridge and valleys (stream) at topographic maps, scale 1:100,000 Silang sheet, and then correlated with the geological maps, Bacan sheet, the volcanostratigraphy units consists of Songa Crown, Pele-pele Hummock, Lansa Hummock, Songa Hummock, and Bibinoi Hummock (figure 2) [8]. This result indicated that there was correlation among the distribution of volcanic rock units and the border of volcanostratigraphy units, so that we could know the distribution of eruption products controlled the morphology of Songa-Wayaua. If there was a difference between the borders of volcanostratigraphy units with the volcanic rocks units in this study, it is due to the border only withdrawn based on morphology, where geological maps used only as a comparison. We also interpreted possible heat source for geothermal system, i.e. of Songa Crown, Pele-pele Hummock, Lansa Hummock, Songa Hummock, and Bibinoi Hummock. The crown on this research area indicated that Songa crown was once an active volcano, from the radial pattern of eroded ridge and drainage pattern. While the hummocks in this area indicated there were still volcanic activity developed below the surface that allowed it to be the heat source.
3.2. Remote Sensing Study Result
The result of lineaments study base on SAR images lineaments show in the figure 3.
Rossette diagram (figure 4) was used to determine dominant trend of lineaments. The result showed that the major lineament trend of the research area was northwest – southeast. This was similar to the regional fault based on geology where Pele-pele Normal Fault, and Bibinoi Fault has some direction. It showed the west part of the research area had northwest-southeast trending direction that became the major structural control thus allowing the surface manifestations existence.

From FFD analysis acquired, the areas that had highest value were on the northwest, southeast, and northeast area of the research. Those areas were interpreted as permeable zone which were estimated as the recharge area of a geothermal system on the research area (figure 5).
Figure 3. Lineaments pattern based on visual observation of Ascending (red) and Descending (blue) images combination overlain on contour lines of topography.
Geological structures which exist on the northwest of the research area indicated the intensity of the tectonic and lithology effect (metamorphic rock). Thus enable the fluid from surface enter the rocks and become the recharge area. But it needs to be studied more with further research to gain more informations. While on the volcanic rocks, the structures enables the fluids from the subsurface to release on the surface and becomes surface manifestations (discharge area).

The calculation of NDVI analysis should be compared to the satellite imagery using natural colour composite to represent actual appearance of the earth’s surface. This step aims to ensure if NDVI index value became low, it was caused by the clouds or manmade. Processing satellite imagery data was done using ILWIS 3.3 and the image was acquired from Landsat 8 OLI satellite which had 11 bands where for the visible red band using band 4 and near infrared band using band 5.

Natural colour composite map displayed that residential area are located around the middle of the island up to the coast towards the northeast and southwest. In addition, at the time of image acquisition, there were clouds on the north, so it was estimated to result low NDVI index value originated from the clouds (figure 6).

![Figure 4. Rose Diagram showed that the major lineament trend of the Songa Wayaua area was northwest – southeast.](image)

To support the analysis, NDVI value of Songa-Wayaua divided into three classes. Low NDVI with value -1.00 to 0.11 was poor vegetation shows in red colour, medium NDVI with value 0.11 – 0.47 shows in yellow colour, and good NDVI with value 0.47 – 1.00 was healthy vegetation and shows in green colour. Furthermore, there was value that could not be determined, valued in white colour, it was alleged because of the limitations of software in calculating NDVI value. Songa-Wayaua area had low NDVI values around the east coast, which was also the residential area. Beside the eastern area, there were also low NDVI values on the southern area of Songa, which was still Geothermal Working Area Songa-Wayaua.
Figure 5. Fault Fracture Density of Songa-Wayua area presented by color scale overlain on contour lines of topography.
Figure 6. Natural color composite map

Figure 7. Normalized Difference Vegetation Index map
From the analysis, it was estimated that geothermal manifestations were on the purple-circled area in the figure 7, while the blue circles were not indicate the manifestations, but the thin clouds covering the vegetation underneath. Geothermal manifestations on the north and southeast were warm springs [15], while those on the south and southwest were still not carried out further exploration yet. Geothermal manifestations in the form of hot spring could not distinguish by this method, because the manifestations were adjacent to the residential area, which already had low vegetation values.

From volcanostratigraphy and remote sensing analysis, were concluded that there is one geothermal system, where Mount Lansa and Mount Songa area had more potential resource [15].

4. Conclusion
Based on the analysis of topographic maps, remote sensing, and regional geology for the geothermal system of Songa-Wayaaua area, there are some conclusions as follows:

- The volcanostratigraphy of the research area are Songa Crown, Pele-Pele Hummock, Lansa Hummock, Songa Hummock, and Bibinoi Hummock. The Crown on this research area indicated the area was once an active volcano. While the hummocks in this area indicated there were still volcanic activity developed below the surface that allowed it to be the heat source in the research area.
- Geological structures of Songa-Wayaaua were dominated northwest-southwest trending, consisting of Pele-Pele Normal Fault. This geological structure was likely to be primary control of Songa-Wayaaua geothermal system area thus allowing the surface manifestations existence. These structures developed at areas with low elevation, which were the central part of the research area, and some along the eastern coastline of the research area. These structures enabled these locations as the discharge area
- From FFD analysis acquired, the areas that had highest value were on the northwest, southeast, and northeast area of the research. Those areas were interpreted as permeable zone. Those areas were estimated as the recharge area of a geothermal system on the research area
- From the NDVI, could be found several vegetation stress locations on research area. It was correlated with the field data, which were several manifestations of warm springs occurred.
- From volcanostratigraphy and remote sensing analysis, we concluded that there is one geothermal system, where Mount Lansa and Mount Songa area had more potential resource than other areas.

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