Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal System and Conceptual Model of Songa-Wayaua, North Maluku, Indonesia

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Keywords: Songa-Wayaua, Geothermal, Conceptual Model.

ABSTRACT

Songa-Wayaua geothermal area is one of the most interesting geothermal areas located in the Bacan Island, province of North Maluku. Surface thermal features in the Songa-Wayaua area consist of hot springs, fumaroles, mud pools, hot grounds, and rock alterations by temperature 65-103.5°C. 3D-surveys have been conducted in 2006 to identify the geothermal system and prospect area of Songa-Wayaua. A 3D-inversion model from gravity data revealed a geothermal system concentrated under Songa graben structure, between Bukit Lansa dan Bukit Pele. The two bodies are the youngest volcanic rocks and estimated as the heat source of geothermal systems in this area.

Geological data of Songa-Wayaua indicate impermeable rocks that have properties with argilic clay mineral (argilic clay cap) on alteration zones near the hot springs. Altered rocks occur in the Quaternary volcanic lava units and Sibela metamorphic rocks. This alteration is also reflected in the zone of magnetic anomalies, which are characterized by zones of demagnetization around manifestation of Babale Lansa, Pelepele and Padopado. Low apparent resistivity (<15 ohm-m) also indicate the presence of a layer of rock alteration due to geothermal fluid interaction with the surrounding rock.

A reservoir is possibly formed in Cretaceous Metamorphic rocks, below the volcanic units, where the volcanic unit itself also has the possibility of becoming a shallow reservoir. The rock which has a density of 2.83 gr/cm^3 is considered suitable to be a reservoir because it has undergone a process of deformation in the Miocene until the Pleistocene period that caused a pattern of intense fractures and permeability.

1. INTRODUCTION

The Indonesian archipelago, which lies in the volcanic arc, is potentially rich in geothermal energy. The Center for Geological Resources has found in 2006 with geological, geochemical and geophysical methods that Songa – Wayaua, is one of the Indonesian islands, has geothermal potential. Songa-Wayaua is an interesting geothermal area, located on Bacan Island in the North Maluku Province. The Songa-Wayaua geothermal manifestations are hot springs, fumaroles, mud pools, steaming grounds and altered rocks with temperatures between 65 - 103.5°C. The author conducted a review of geoscience data and created a conceptual model of the Songa - Wayaua geothermal area in order to identify geological, geochemical and geophysical characteristics.

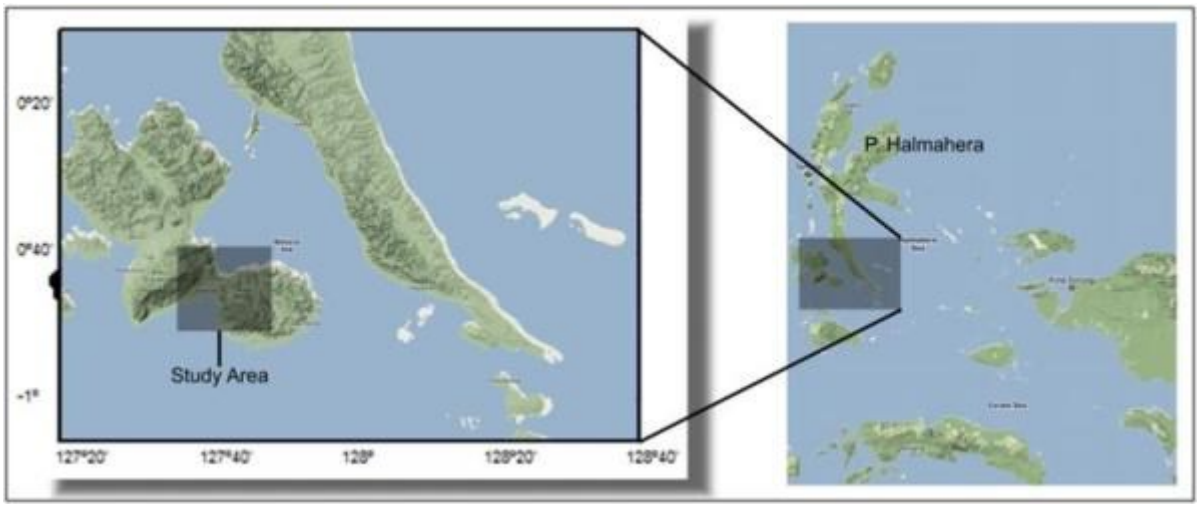

Figure 1: Map with location of Songa – Wayaua.

2. METHODOLOGY

The methodology applied is compiling the data contained in geoscience research reports and earlier scientific papers, reflecting the picture of the subsurface geothermal system of Songa - Wayaua which includes a heat source, reservoir layer, cap rock layer and hydrothermal. Lineament interpretation of geological structures on Landsat and ASTER GDEM is used to understand the boundary of the geothermal system and volcanism in Songa - Wayaua. Furthermore, we correlated geochemical and geophysical data to draw estimated isothermal subsurface lines. A subsurface overview with a geological cross-section was also compiled. The final result is

a conceptual model of the Songa - Wayaua geothermal system which is reconstructed in an integrated manner to obtain a more informative picture.

3. GEOSCIENCE REVIEW

The existence of manifestations controlled by the southwest-northeast Pele Fault is clearly recognizable by the horizontal gravity gradient. Manifestations in the coast of Gulf Lapan are located at a Bouguer low anomaly in response to fractured rocks by geological structures and hydrothermally altered. The alteration zone is reflected also by the demagnetization zone surrounding manifestations. Low apparent resistivity indicates a change due to hydrothermal interaction with the surrounding rocks scattered from north to south. The thickness of the alteration rock layer is estimated at more than 500 m which plays a role as cap layer. Underneath is a reservoir layer, the location of hydrothermal accumulation. With gravity inversion modeling, a trend is visible of rock layers with rising density at depths larger than 750 meters. It is estimated as boundary of the cap and reservoir layer. Gravity and magnetic modeling shows the presence of two bodies of rock with a high density and high magnetic characteristic. Geologically these two bodies are the youngest volcanic rock (Bukit Lansa and Bukit Pele), estimated as heat source for the geothermal system.

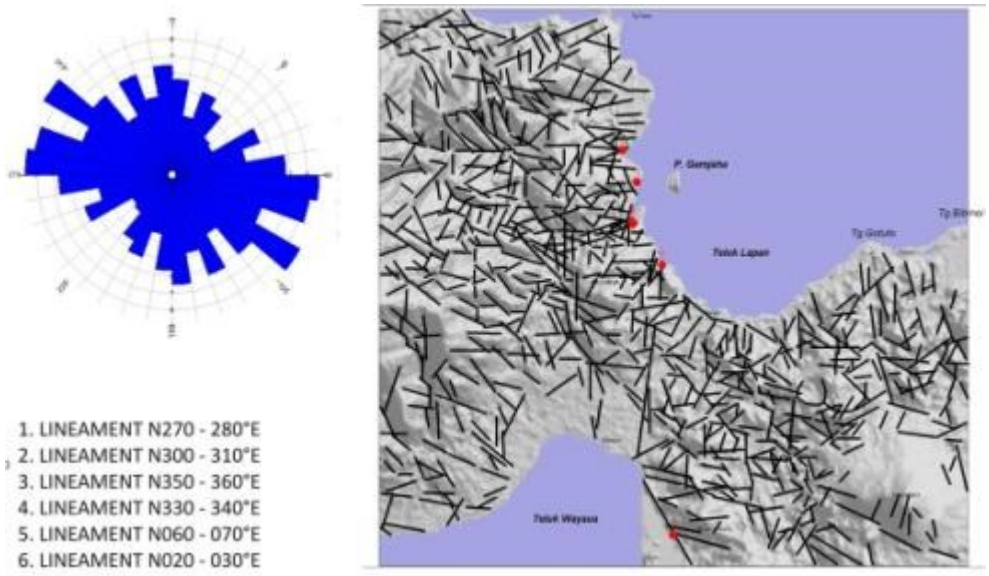

Figure 2: Structure analysis from lineament on Songa - Wayaua.

The analysis from the geological structure data showed that an anomaly of density of faults and fractures is seen around hot springs area in Songa and slightly widened to the west, while the results from geochemical analysis data show high Hg anomalies and high CO_2 anomalies scattered around Pelepele coastal hot springs and Great Pelepele hot springs.

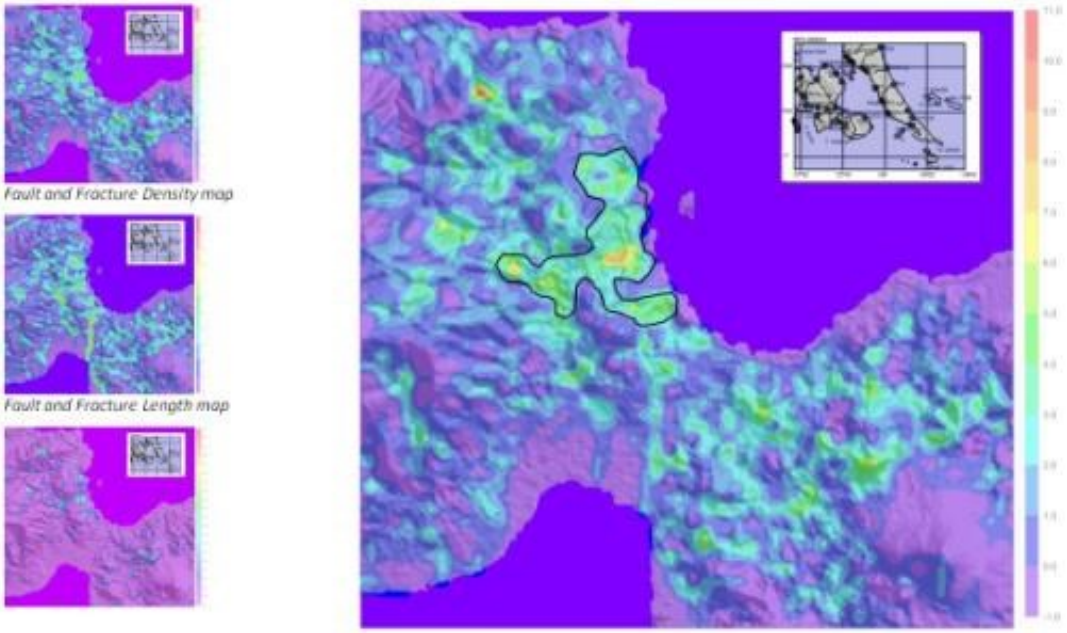

Figure 3: Fracture density map of Songa – Wayaua

Geophysical data showed that a Bouguer gravity low anomaly can be found surrounding the manifestations. It is estimated that they are associated with low density rocks due to the interaction between hydrothermal with that rocks and also abundantly fractures of the rocks. This data is also supported by magnetic anomalies (demagnetization zone) as shown by the relatively low magnetic anomaly when compared with high magnetic anomaly which is the response of the volcanic rocks by Bukit Lansa and Bukit Pele products. Further, the magnetic anomalies are relatively high when compared with anomaly values of metamorphic rocks that are in the Mount Sibela. Based on resistivity data, a low apparent resistivity distribution is found, associated with rocks alteration, scattered north of the Padopado hot springs and widened towards the southern Babale Lansa hot springs with patterns that open towards the sea. The results of the analysis and compilation of the three methods of geological, geochemical, and geophysical data show that geothermal prospect areas tend to be concentrated in Songa areas (e.g. Padopado hot springs, Pelepele Coastal, Great Pelepele, and Babale Lansa) with an area of approximately 14 km^2.

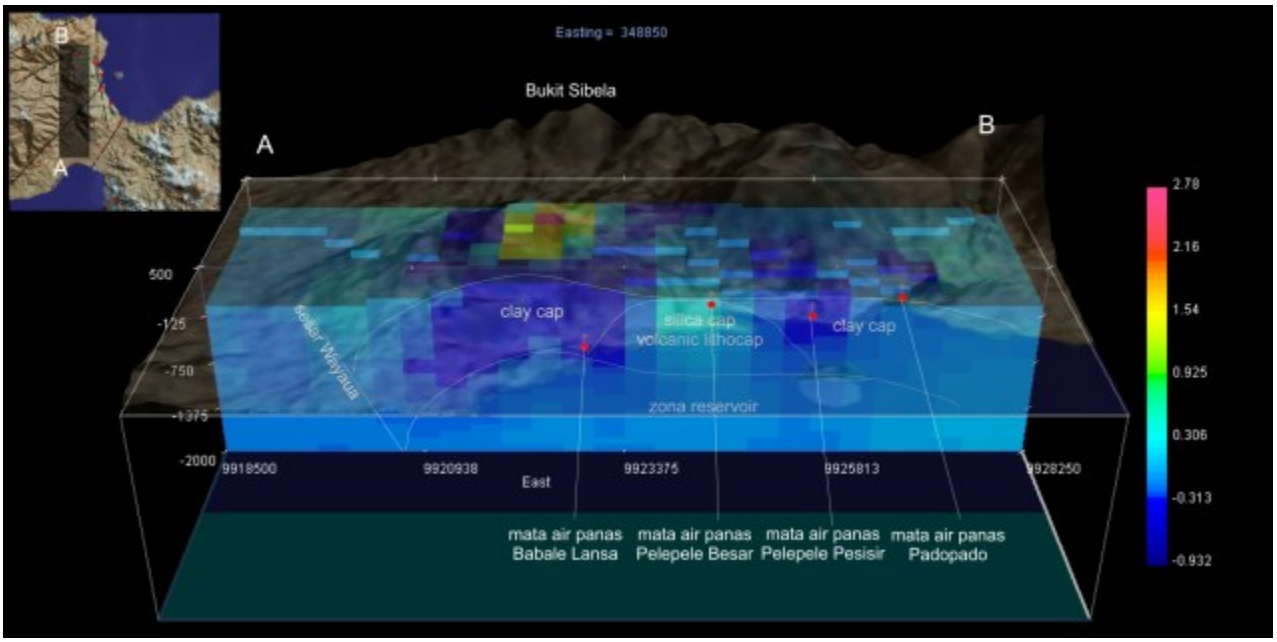

Figure 4: Interpretation of geothermal system of Songa-Wayaua based on gravity model (Zarkasyi and Rezky, 2011).

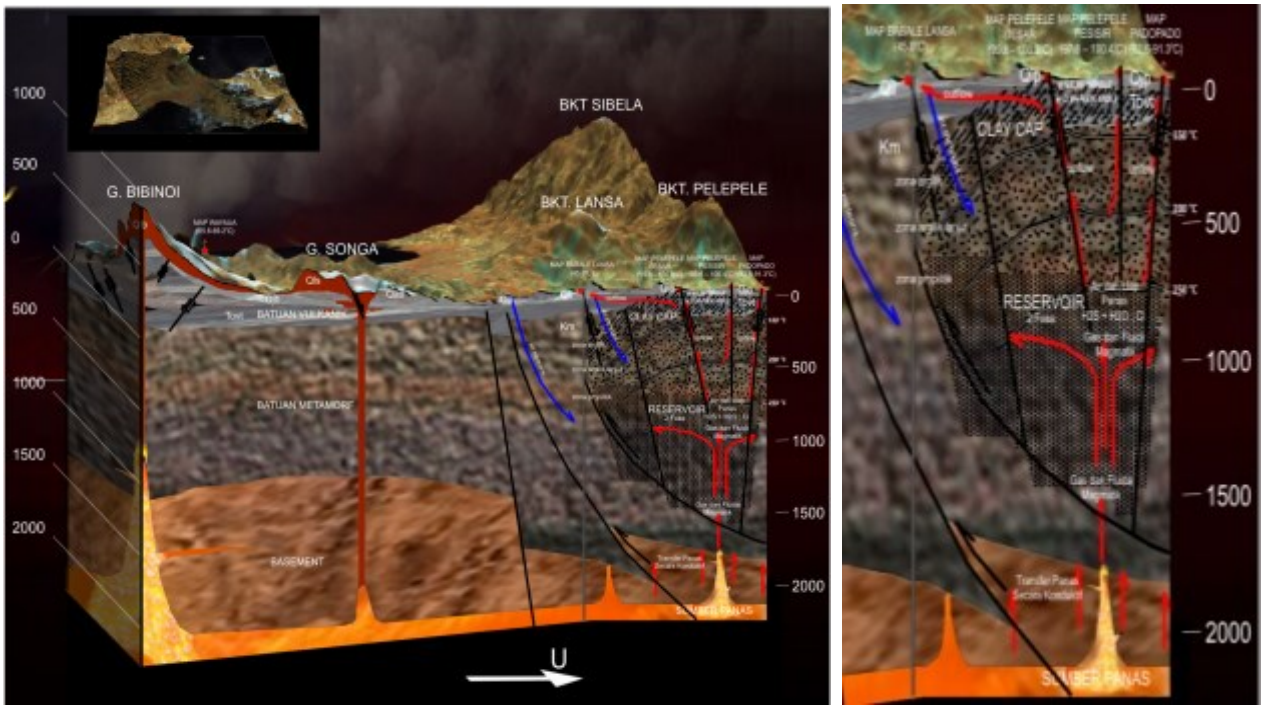

Figure 5: Conceptual model of Songa-Wayaua.

4. DISCUSSIONS

The rocks which allow forming of the reservoir are a product of Cretaceous Metamorphic Sibela which is below volcanic units. The volcanic unit itself also has the possibility of becoming a shallow reservoir. These rocks have a density of 2.83 gr/cm^3 which is considered good enough for a reservoir because, through a process of deformation in the Miocene to Pleistocene periods, it obtained an intense fractures pattern with good permeability. The top of the reservoir is at a depth of 500-750 m below sea level with a thickness that cannot be delineated based on existing geophysical data. But from gravity inversion modeling, it was shown that trending of rock layers with higher density is at depths deeper than 750 meters. It is estimated that at this depth is the boundary zone of the caprocks layer and the reservoir. Then with the approach of surface geological interpretation, it is estimated that the lower boundary of the reservoir is limited by thrust fault which lifts metamorphic rocks and ophiolite to the surface which are estimated at 1250-1500 m depth below sea level. Thus, the thickness of the reservoir is estimated to be 750 to 1000 m.

5. CONCLUSIONS

Alteration rock layer thickness is estimated to be more than 500m which acts as the cap layer. Underneath is the reservoir layer, from depths > 750 meters with an estimated thickness of 750 - 1000m. The rocks which allowed to form a reservoir is the product of Cretaceous Metamorphic Sibela which lays below volcanic units. These volcanic units also have the possibility to become a shallow reservoir. The heat source of the geothermal system in Songa - Wayaua comes from the youngest volcanic activity which is the Bukit Lansa and Bukit Pele.

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