BONJOL GEOTHERMAL TENTATIVE MODEL BY USING 3G (GEOLOGY, GEOCHEMISTRY AND GEOPHYSICS) ANALYSIS

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ABSTRAK. Geothermal exploration is rapidly done in Indonesia. One of Indonesia prospect is Bonjol Geothermal area, West Sumatera. In order to develop geothermal indirect use (power plant energy source) in this area, we need to understand its geothermal system by built a tentative model from integrated 3G data. Geological analysis use Landsat 8 band thermal, alteration map and geological map. Landsat 8 band thermal used to determine vegetation density (normalized difference vegetation index transformation) and also surface temperature structure. Geological map used to locate major structure and lithology distribution as boundary of geothermal system. Fault and fracture density (FFD) map from DEM SRTM analysed using lineament pattern related with fault and fracture. Alteration map using spectral value of mineral used to understand geothermal system indication. Geochemical analysis use hot spring manifestation (neutral pH hot springs with temperature ranging from 49.7°C to 87.9°C) to characterize geothermal system type and determine reservoir temperature. Chloride type of hot spring manifestation indicate a hot water dominated system. Geophysics analysis use 13 sites of magnetotelluric (MT) time series data. Processed by Fourier transform, robust processing, and crosspower selection. The MT data is not rotated referring to its geoelectrical strike (0°). Then the data inversed to become 2D MT resistivity model. Subsurface condition imaged by magnetotelluric 2D resistivity model, it shows Bonjol’s cap rock and reservoir distribution and geometry also indication of structure. The subsurface alteration and structure distribution generated using surface structure and alteration map. Subsurface isothermal model generated by using geochemistry model. We integrate geology, geochemistry and geophysics data to build Bonjol tentative model.

Kata kunci: Geothermal, Landsat 8, Magnetotelluric, Tentative Model, Bonjol

I. INTRODUCTION

Geothermal energy is an energy generated from natural heat transfer, which is from a heat source to the surface by free convection, involving meteoric fluids with or without traces of magmatic fluids (Hochstein and Browne, 2000). This energy is renewable and can be used in a relative long time. As the result, this energy can be an alternative solution on facing of recent world energy crisis problem. In fact, this energy is a clean and environmentally friendly. The exploration development of this energy is reasonable considering the abundance of its occurrence in Indonesia. Bonjol area is one of geothermal field are in Pasaman Regency, West Sumatera Province, which is lies along volcanic mountain. Bonjol area has a promising geothermal potential, as indicated by surface manifestation in the form of hot spring. This surface manifestation is showing
natural condition of the presence of geothermal resources. As the further studied is necessary to know the potential energy of that area.

II. METHODOLOGY

II.1. Geology

Geological analysis generate 4 GIS (Geographic Information System) map which are NDVI (Normalized Difference Vegetation Index) map, LST (Land Surface Temperature) map, LD (Lineament Density) map and alteration map. NDVI map, LST map and LD map method refer to Hakim et. al., (2017) research on reconnaissance stage at Bur Nj Telong volcano geothermal area. Vegetation index determined by NDVI transformation using NIR wave (band 5) and red wave (band 4) from Landsat 8. Land surface temperature map use band 10 from Landsat 8 by inversion of Planck’s function algorithm. Density lineament map generated using DEM SRTM data with Fault and Fracture Density method. This method assume any lineament as a fault and fracture as hot fluid pathway. Lineament taken by compare it with regional structure (geological map) to differ fault and fracture with other structure (anticline, river, etc.).

Alteration map conducted by referring to Knepper (2010) research on locating the distribution of potential hydrothermally altered rocks in Central Colorado. It preparation through two steps which are applying various image processing procedures designed and filtering the result also convert it to ArcGIS vector shape files.

II.2. Geochemistry

The Bonjol geothermal geochemical study uses a literature study method. The literature used is "Geologi dan Geokimia Daerah Panas Bumi Bonjol Kabupaten Pasaman, Sumatera Barat" by Dedi Kusnadi, Dikdik Risdianto, and Sutoyo (2007). Geochemical testing of hot springs is located in 4 places namely Takis hot spring, Sungai Limau hot spring, Kambah hot spring, and Padang Baru hot spring.

II.3. Geophysics

Geophysics analysis use 13 sites of magnetotelluric (MT) time series data, 6 sites on line 1 and 7 sites on line 2. Line 1 across a hot spring and line 2 across two hot springs (figure 1). Processed by Fourier transform, robust processing, and crosspower selection. The MT data is not rotated referring to its geoelectrical strike (0o) according to Weaver (2010) and Bahr (1988) directionality tools. Then the data inversed to become 2D MT resistivity model using Non Linear Conjugate Gradient method by Rodi and Mackie (2001).
Figure 1. Magnetotelluric design survey map

Figure 2. Research Workflow
III. RESULT AND DISCUSSION

3.1. Geology

Figure 3 show a classification of densely vegetated land, deforested land, mixed and dense vegetation, and water-covered land. Land that has dense vegetation in the figure is indicated by green with NDVI > 0.6. Mixed land of dense and bald vegetation is shown in yellow which has a value of 0.2 ≤ NDVI ≤ 0.6. The bare land is shown in orange in the image that has a value of 0 ≤ NDVI < 0.2. Water-covered land is indicated by red in the image that has NDVI value < 0. Based on the NDVI value, most of the study area is dense vegetation mixed vegetation land.

![NDVI map of Bonjol geothermal area.](image)

LST map (figure 4) of the study area will be determined after NDVI, which can be obtained from Landsat 8 OLI thermal sensor image processing on January 17, 2019 (USGS). The surface temperature in the study area is processed using band 10 Landsat OLI images because the band 10 is better compared to band 11. The results of the
calculation of soil surface temperature require the value of soil emissivity which obtained with the help of NDVI.

**Figure 4.** LST map of Bonjol geothermal area.

Based on figure 4, LST values in the study area ranged between 20°C and 30°C. Most of the study areas have LST 20°C-25°C indicated by blue areas. The distribution of highest LST is in the south, east and center of the study area. The area has a relatively
high LST according to two faults on the geological map, so it is very likely that the hot fluid is close to the surface, this is consistent with the statement that faults are associated with high soil surface temperatures.

**Figure 5.** LD map of Bonjol geothermal area.
Lineament density map (figure 5) values are classified into three classes, low class (0–0.25 km/km²), medium class (0.25–0.50 km/km²) and high class (0.50–0.78 km/km²). High-class lineament density value which is symbolized by dark blue. Geothermal manifestations are traversed by faults or fractures in medium lineament density (bright blue area). Thermal manifestations occurred in low gray lineament density in areas without lineaments or faults. Semangko Fault also affect the direction of lineament. NW–SE lineament follow the pattern of Semangko Fault, but because of its remote location, the direction of these lineament is not more dominant than the direction of the East-West lineament which predicted to be local faults.

Figure 6. Landsat Thematic Mapper (TM) potentially hydrothermally altered rocks of Bonjol geothermal area.

3.2. Geochemistry

Table 1. Water Analysis Data, Bonjol Geothermal Prospect, Pasaman District, Sumatera Barat Province

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>TAKIS HOTSPRING</th>
<th>SUNGAI LMAU HOTSPRING</th>
<th>PADANG BARU HOTSPRING</th>
<th>KAMBAHAN HOTSPRING</th>
<th>BATU AMPA COLDSPRING</th>
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<tbody>
<tr>
<td></td>
<td>APT</td>
<td>APL</td>
<td>APPB</td>
<td>APK</td>
<td>ADB</td>
</tr>
<tr>
<td>Elev (m)</td>
<td>243</td>
<td>289</td>
<td>222</td>
<td>259</td>
<td>343</td>
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<tr>
<td>T(°C) air</td>
<td>87.9</td>
<td>73.5</td>
<td>49.7</td>
<td>73.4</td>
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</tr>
<tr>
<td>T(°C) udara</td>
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<td>30.6</td>
<td>29.0</td>
<td>27.4</td>
<td>25.2</td>
</tr>
<tr>
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</tr>
<tr>
<td>EC</td>
<td>3300</td>
<td>4040</td>
<td>5430</td>
<td>2020</td>
<td>17</td>
</tr>
<tr>
<td>(uf/cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SiO₂ (mg/L)</td>
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<td>190.60</td>
<td>94.00</td>
<td>101.00</td>
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<td>Al</td>
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<td>0.00</td>
<td>0.19</td>
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<td>Ca</td>
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<td>Na</td>
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</tr>
<tr>
<td>Li</td>
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<td>Aš</td>
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<tr>
<td>B</td>
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<td>9.46</td>
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<td>F</td>
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<td>0.00</td>
<td>0.00</td>
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<td>1336.86</td>
<td>580.48</td>
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<td>114.15</td>
<td>327.97</td>
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<tr>
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<td>120.00</td>
<td>906.39</td>
<td>93.83</td>
<td>2.51</td>
</tr>
<tr>
<td>CO₃</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
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<td>33.57</td>
<td>55.42</td>
<td>18.15</td>
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</tr>
<tr>
<td>meq an.</td>
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<td>19.20</td>
<td>0.04</td>
</tr>
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<td>-3.41</td>
<td>-3.50</td>
<td>-2.81</td>
<td>-3.75</td>
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</table>

To know the characteristics and the type of hot water from data of chemical composition, triangle diagram of Cl - SO₄ - HCO₃, Na-K-Mg, and Cl-Li-B was used (Giggenbach, 1988).

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Figure 7. Hot spring map

Based on Fig 8, the hot springs in Bonjol district are Takis hot springs, Limau river hot springs, Kambahan hot springs, and Padang Baru hot springs which are located in position of chloride. Concentration of chloride is higher than that of SO₄ and HCO₃, probably being derived from deep geothermal reservoir. The hot vapor fluid, related to source of geothermic interaction with rock around it, happened blending with surface water to form appearance of hot spring which had neutral pH (6.50-7.50).

Figure 8. Triangular diagrams Cl-SO₄-HCO₃ (Dedi Kusnadi et. al., 2007)

In the triangle diagram of Na-K-Mg (Fig 9), the positions of Takis hot spring, Sungai Limau hot spring, and Padang Baru hot spring lay in partial equilibrium, which indicates that manifestation emerges to equiamplitude surface influenced by interaction
between fluids and rocks in a state of temperature before mixing with surface water (meteoric water). Except that Kambahan thermal spring lays in immature water, from the fourth position of hot spring in the diagram, there is a straight line to the temperature around 100 – 160 °C (Na-K). If pulled line to parallel K-Mg, it will fall at different temperatures, which shows that the temperature is smaller than the value from Na-K.

On Cl, Li, B (Fig 10) diagram fourth position of located thermal spring lead to middle position of the diagram. Existence of interaction between hot fluids with geothermic rock need to be supported by isotope analysis from hot and cold springs. Hot spring sample lies position in the right side from meteoric water line (18O shift). Indication of existence is Oxygen 18 from hot water spring mentioned above, result reaction substitution O 18 from Oxygen 16 from thermal fluid when consist interaction thermal fluid and rock before emerge surface like hot spring.

![Figure 9. Tiangular diagrams Na-K-Mg (Dedi Kusnadi et. al., 2007)](image)

![Figure 10. Tiangular diagrams Cl-Li-B (Dedi Kusnadi et. al., 2007)](image)
3.3 Geophysics

Magnetotelluric method which described subsurface resistivity structure could use to determine Bonjol geothermal system components. Low resistivity zone (<10 Ohm.m) showed in red on the 2D magnetotelluric resistivity model interpreted as cap rock caused by conductive alteration. Reservoir with moderate resistivity zone (10 – 120 Ohm.m) showed in green with high resistivity with permeable zone caused by alteration and fluid accumulation. Heat source with high resistivity zone (>120 Ohm.m) showed in blue caused by high resistivity hot igneous rock. The lateral discontinued resistivity interpreted as fault, this could bound geothermal prospect area.

Line 1 (figure 11) show two faults (Alahan Mati and Bonjol) and two fault indications (Padang Baru and unidentified fault), cap rock, reservoir and heat source. Faults bound the cap rock alteration process which also bound geothermal prospect area and also as discharge area such Padang Baru fault indication. Line 2 (figure 12) show three faults (Alahan Mati, Padang Baru and Bonjol) and a unidentified fault indication. The cap rock whose hold hydrothermal fluid only occur on the right side because of its geometry.

![Figure 11: Line 1 2D magnetotelluric resistivity model of Bonjol geothermal area](image-url)
3.4. Conceptual Model of Geothermal System

From the geothermal flow direction data, it can be compared with the geothermal system model from the 2009 PSDG research in the Bonjol area. From this comparison, it was found that Bonjol is located in a valley formed by fault activity. This zone allows the emergence of hot springs as a manifestation of geothermal energy.

Figure 12. Line 2 2D magnetotelluric resistivity model of Bonjol geothermal area

Figure 13. Conceptual Model of Bonjol Geothermal System
IV. CONCLUSION

Based on the map observations and interpretation of the method used, the researcher can conclude:
1. The hot spring manifestations in this area are controlled by lithological factor and geological structure of the research area.
2. Hot spring manifestation at Bonjol geothermal system has type of chloride water with temperature range on 100-160° C.
4. Hydrothermal alteration map differ color-ratio composite mosaic image based on three classes of potentially hydrothermally altered rocks. (1) Clay – Carbonate – Sulfate (2) Clay – Carbonate – Sulfate- Ferric Iron and (3) Ferric Iron (4) Ferric Iron – Bare Rock-Soil (5) Bare Rock-Soil and (6) Clay – Carbonate- Sulfate – Bare Rock-Soil (7) Clay Carbonate-Sulfate with hot spring area at zone (5)
5. Hot spring area has a high fracture density on FFD map, but not every high fracture density show a manifestation.
6. Surface temperature distribution quite evenly ranging between 20°C to 30°C. So, exploration stage suggested to focus on area with hot spring manifestation.
7. NDVI result show most area as a dense vegetation zone.
8. MT model show a geothermal system with cap rock, reservoir, heat source and also fault on Bonjol geothermal prospect area.
9. Line 1 2D MT model indicate an ideal geothermal system geometry with a wide cap rock area.
10. Bonjol area has the potential as a power plant with further study by relevant parties.

REFERENCES


