Identification of Geothermal Potential with Remote Sensing, Geochemistry, and Magnetotelluric Method in West Sumatera

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Abstract

West Sumatra is one of a geothermal potential in Indonesia because of interaction between Eurasian and Indo-Australian tectonic. The existence of volcanoes produces geothermal potential with lithology andesite, tuff, and lapilli lava in the Marapi Mountain complex, which elongated at NW-SE direction as a result of NE-SW subduction. The remote sensing method specifically with Composite Band 567 and Lineament Density Analysis (LDA) found anomaly with the permeability value of prospects ranged from 2.05 to 4.76% per km^2 (highest density value) with general direction is in the southeast-northwest which in line with the Sumatra structural pattern. Based on geological data, argillic alteration was found with geothermal manifestations consisting of hot springs. Through geochemical analysis, the fluid type of hot water sample (temperature of 48.66^{o}C) is in the immature water zone; occur with the presence of carbonate sinter. Geophysical analysis using the magnetotelluric (MT) method to identified geothermal systems such as cap rock with low resistivity (<30 ohm.m) and reservoirs with moderate resistivity (31-300 ohm.m). The correlation between remote sensing, geochemistry, and magnetotelluric could determine the geothermal potential in West Sumatra.

Keywords: *geothermal, remote sensing, geochemistry, magnetotelluric*

I. Introduction

Geothermal is an alternative energy that is environmentally friendly to reduce dependence on oil and gas energy. Indonesia have largest geothermal energy in the world with around 29.215 MW or around 40% of the world's reserve [1]. Region in Indonesia that shows indication of a geothermal energy resourse is in the West Sumatera (Fig. 1) with one of geothermal manifestations consist of hot water group with a temperature of 48,66 ^{o}C and air temperature 22.56 ^{o}C in the immature water zone occur with the presence of carbonate water [2].

The location of geothermal energy resourse that geographically located at coordinates 100^{o}26'15,81" – 100^{o}37'02,77" BT and 0°21'42,59" – 0°30' 55,78" LS near the Marapi Mountain which administratively include in West Sumatera [3]. The remote sensing method with Composite Band 567 and Lineament Density Analysis (LDA) is to identify permeable zone with straightness that was controlled by geological structure that produce topographic alignments such as ridges and depressions. Then, geochmestry analysis is classifying of manifestation type, observation temperature, or pH. Beside that, magnetotetelluric is to known the geothermal system with resistivity value [4]. The purposes of this research are identify the geothermal potensial using correlation between remote sensing, geochemistry, and magnetotelluric method in West Sumatera.

Figure 1. The location of research on West Sumatera.

II. Materials and Methods

A. Surface Temperature

In the process of surface temperature analysis using the band 10 Landsat 8 Oli / TYR. This analysis can produce temperature values that are useful for the initial exploration of geothermal associated with average temperatures [5]. The initial step is to insert band 10 into ArcGis 10.2 software and convert the DN value to the value in Band 10 with the equation.

$$L\lambda = ML\, Qcal + AL \tag{1}$$

Where Lλ, ML, Qcal are Toa Spectral Radiance, band specific multiplicative rescaling factor from the metadata, and band specific additive rescaling factor from the metadata.

After entering the formula, then the DN value will change to radians and the surface temperature value will be obtained to be one of the determinants of further exploration areas.

B. Band Composite

Composite band 567 uses several bands in Landsat 8 Oli / TIRS to facilitate in knowing surface information such as land cover, geological structure, surface texture, and water body. The first step is to put band 5 as Red channel, 6 as Green channel, and 7 as Blue channels. Then do a composite process that will later produce a color that is different from natural color and can draw better surface information.

C. Lineament Density Analysis (LDA)

Topographic or linear tonal features on the surface of the earth that represent zones of structural weakness can be produced by a lineament refer to Fig. 2. If lineament density can be mapped, information about the permeable zone in an area will be obtained [6].

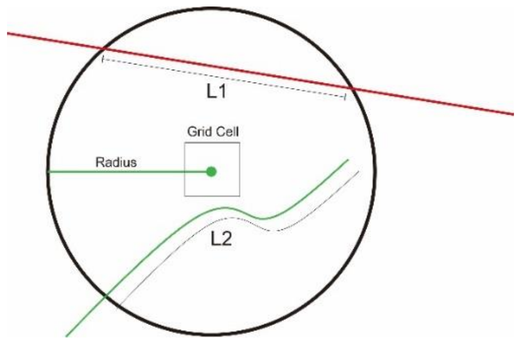

Figure 2. Raster cells and circles to calculate lineament density.

The lineament density calculation process can be illustrated by Figured 4 which contains a raster cell and a circle with a certain radius, lines L1 and L2 representing the length of a portion of the lineament covered by the circle radius (r). The equation for calculating lineament density in each of the cells is.

$$\rho = \frac{L1+L2}{2\pi r} \tag{2}$$

And calculation of lineament density in general can be done with the equation.

$$\rho = \frac{\sum_i^n L1}{2\pi r} \tag{3}$$

From the result of calculation and analysis will produce a contour or color inconsistency that illustrates the density of the straightness (Fig. 3) that can be assumed as a surface permeability value that can be applied in geothermal exploration [7].

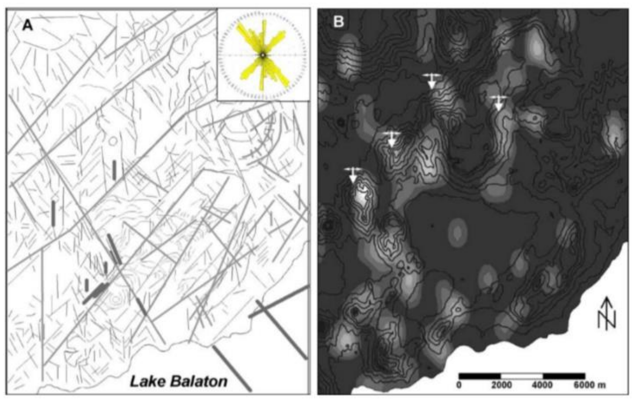

Figure 3. Example of the results of making Lineament Density Analysis. Left : Lineament, Right : Lineament Density.

D. Magnetotelluric

The magnetotelluric method is an electromagnetic sounding method to find out the under surface type resistive structure by passively measuring the electrical field component (E) and the changing natural magnetic (H) field over time [8]. The ratio between the electric field and the magnetic field is called the impedance which is the electrical properties (conductivity or resistivity) of the medium [9]. Electromagnetic waves (EM) that interact with the earth are field waves parallel to the earth's surface and radiate in the direction perpendicular to the medium (earth). The basic concept of the magnetotelluric method is at a point of observation to be investigated (Fig. 4), the value of the subsurface rock type resistance can be determined by measuring the electric field tangential and magnetic fields of electromagnetic waves derived from nature or rock [10].

Magnetotelluric data obtained from the field is in the form of time series data, calibration data, and site parameter data which will be processed by SSMT 2000 software to convert into frequency domain data. After that smoothing will be carried out on crosspower at each frequency with MT-Editor software. Then the inversion was done to produce 1D and 2D modeling with Winglink software [11].

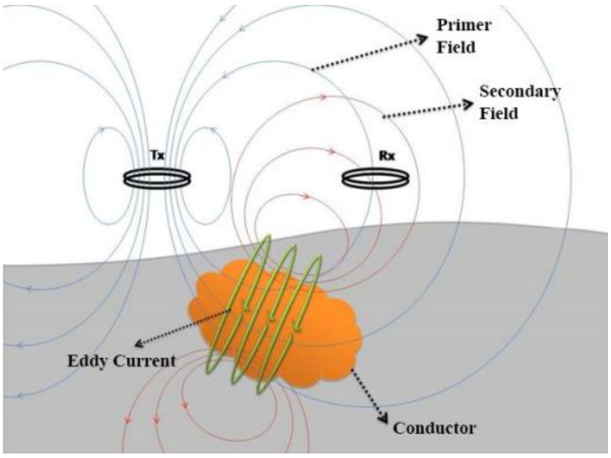

Figure 4. Electromagnetic field induction.

III. RESULTS AND DISCUSSIONS

A. Geology

The rock stratigraphy is divided into, slate, metalimestone, metasandstone, granite, quartz sandstone, conglomerate, old pyroclastic fall, Raja old vulcanic product, lava Pra Marapi, Marapi Fall Pyroclastic, Marapi pyroclastic flow, Marapi lava, Marapi lahar, Sibakaljawi lava, Sibakaljawi pyroclastic flow, Sibakaljawi pyroclastic fall, Parapati lava, Parapati pyroclastic flow, Parapati pyroclastic fall, Gantung lava, Gantung pyroclastic flow, Gantung pyroclastic fall refer to Fig. 5 [12]. Rock alteration, chloritization and argillic zones. The location of alteration of rocks is around Galogadang and Sungayan. Modified minerals found in the Pariangan geothermal field include, among other things, secondary quartz, carbonate minerals, epidote, chlorite, sericite, illite, kaolinite, little, sericite, monmorillonite, halocytes, paragonite, phengit, and nontronite [13].

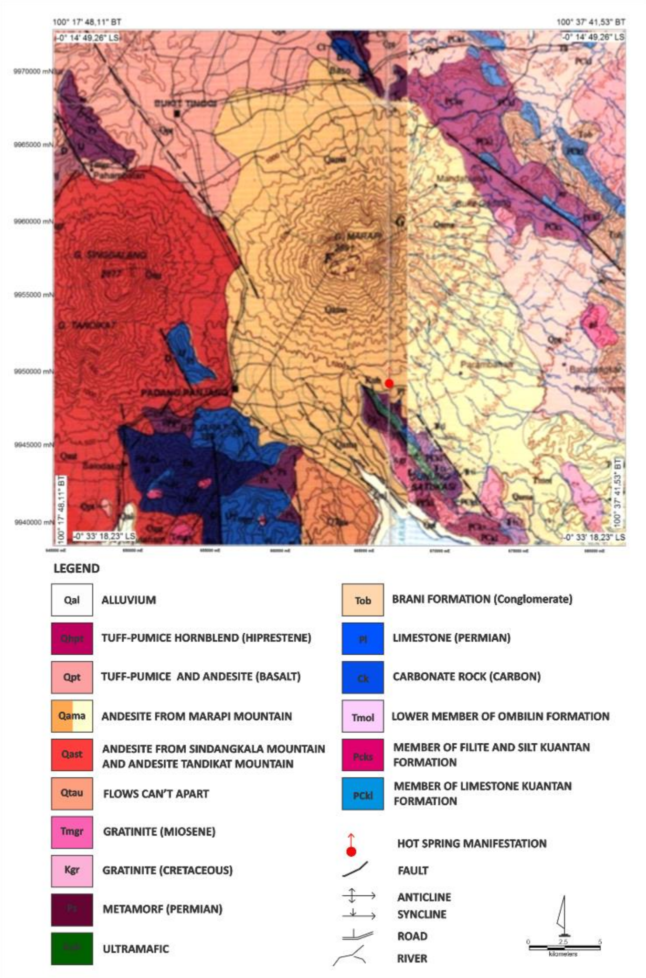

Figure 5. Geological map of research's location.

The geological structure that developed in the area of investigation was influenced by the tectonic activity of the Sumatran fault and the radial fault pattern following the development of the volcanism of the Marapi complex. Based on the lineament and field data, the main pattern of fractures and faults is trending northwest-southeast and the second order is the alignment of the southwest-northeast fault which is likely to be antithetic of the main fault and the third order is a fracture trending almost north-south.

B. Surface Temperature

The highest surface temperature is located around the manifestation area, south and northwest of the research's location (Fig. 6). Many factors can affect surface temperatures ranging from activities caused by geothermal fluids, volcanism, to human activities. It is interpreted that high temperatures in the South and North West part of research's location are affected by human activity, but at high temperatures close to the area of manifestation, caused by temperatures from geothermal fluid activity.

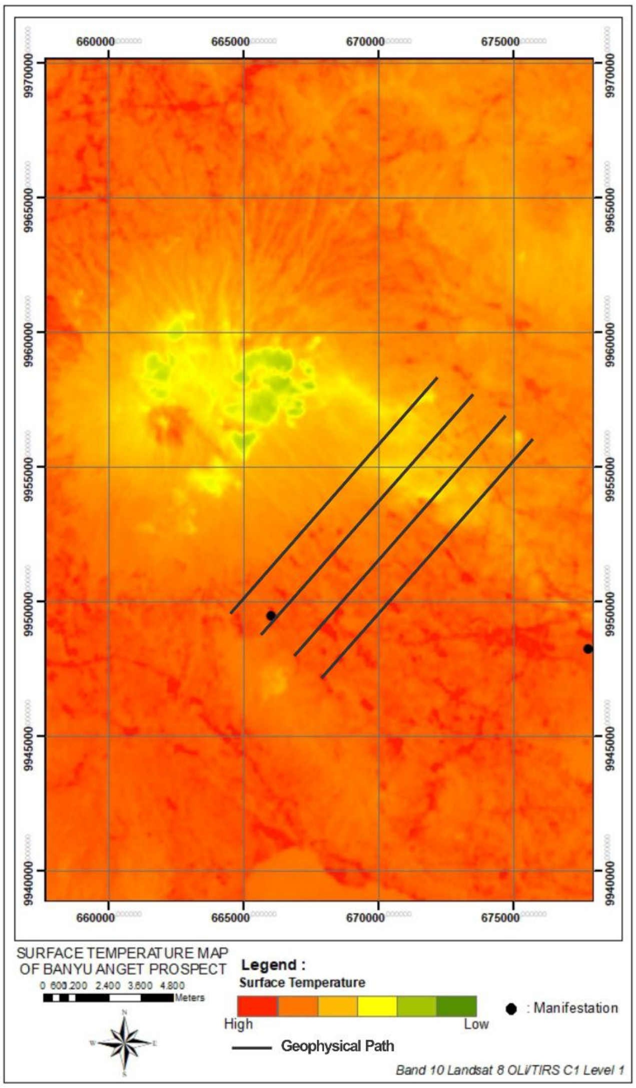

Figure 6. Surface temperature map of research's location.

C. Remote Sensing

The composite band 567 image can provide more detailed information about the geological conditions than the natural color image, where several geological lineaments are detected. The straightness appearance is clearly shown in greyish blue color, and plant density can be observed properly because it gives different color intensities from orange to brown old refer to Fig. 7. This composite band also makes it easy in the process of Straightness analysis in the LDA process.

Lineament Density analysis is an initial exploration study that is used to narrow the exploration area to carry out continued exploration of detail. Based on Lineament Density data, we obtain several classes of density values that can describe the value of surface permeability, this assumption can help in the process of geothermal exploration associated with geothermal fluid pathways to produce geothermal systems and surface manifestations. Anomaly with the permeability value of prospects in this study ranged from 2.05 to 4.76% per km^2 refer to Fig. 8. So in further exploration process can be done in the area with the highest density value, the area is generally located in the middle of the initial research area. Also obtained an average length of lineament length of 2280.14 m. The general direction in the alignment area is in the southeast-northwest which is in line with the Sumatra structural pattern and the general fracture direction of the research's location.

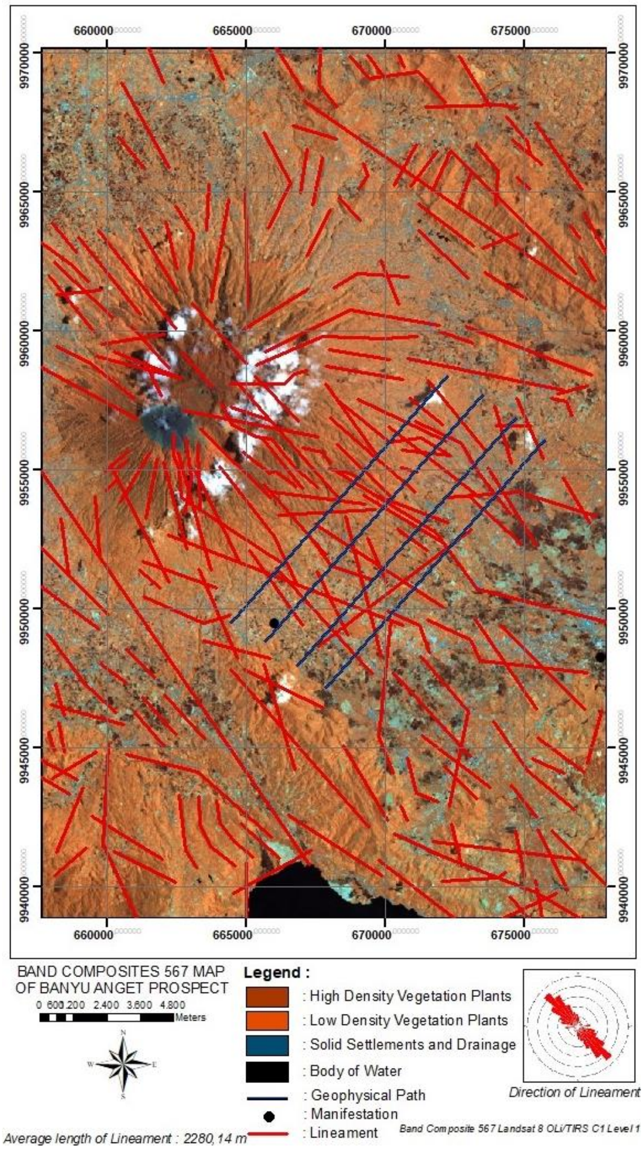

Figure 7. Lineament map of research's location.

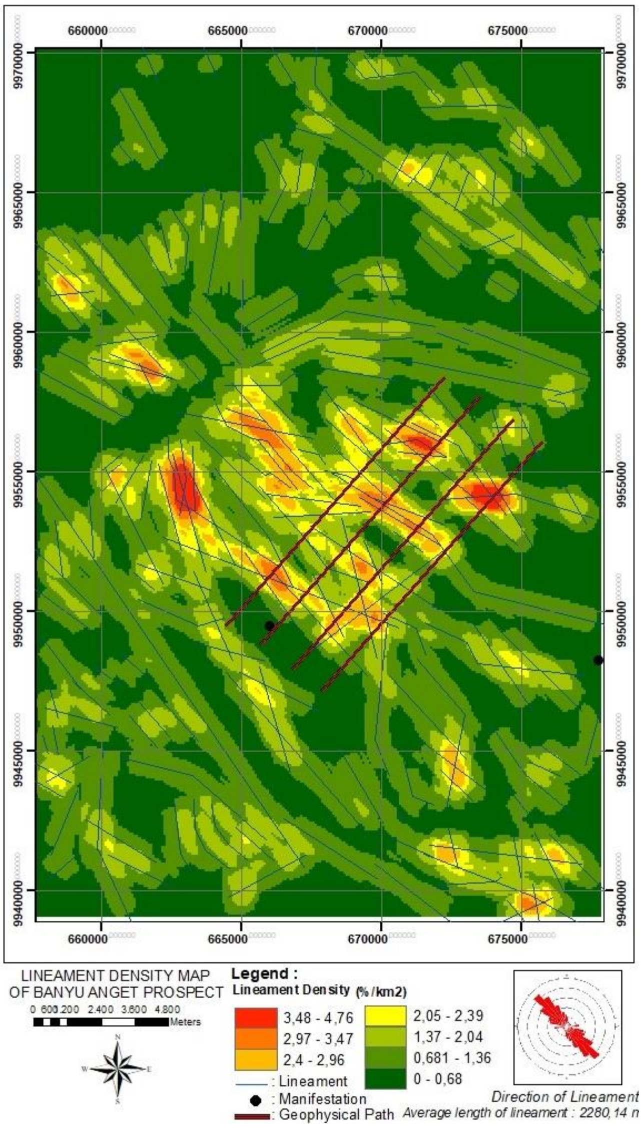

Figure 8. Lineament density map of the research's location.

D. Geochemistry

The geochemical data was collected are 10 water samples and 137 soil samples in the Pariangan geothermal field [14]. The appearance of geothermal manifestations consists of Pariangan hot water group with a temperature of 48.66°C, air temperature of 22.56°C, pH 6.25, DHL power of 2900 µS / cm, discharge of 2 L / sec, and there is a carbonate sinter. Sopan boiling hot water, appears in the rice field temperature of 34.60°C at 25.90°C, pH 6.08, DHL 1900 µS / cm, discharge 2 L / sec. Batu Basa warm water, appears in metamorphic rocks, temperature 32.00°C, air temperature 24.67°C, pH 6.80, DHL 560 µS / cm and discharge 2 L / sec. Galo Gadang warm water, appears in the area of released rocks, warm water temperature of 30.59°C, at an air temperature of 25.30°C with a pH of 6.25, electrical conductivity of 550 µS / cm and a discharge of 0.5 L / sec.

Based on the SO4-Cl-HCO3 plotting diagram (Fig. 9) classifying all hot water in the Pariangan and surrounding areas as bicarbonate type, while the Koto Baru water is acid sulfate water type, indicating the influence of the active volcano Marapi.

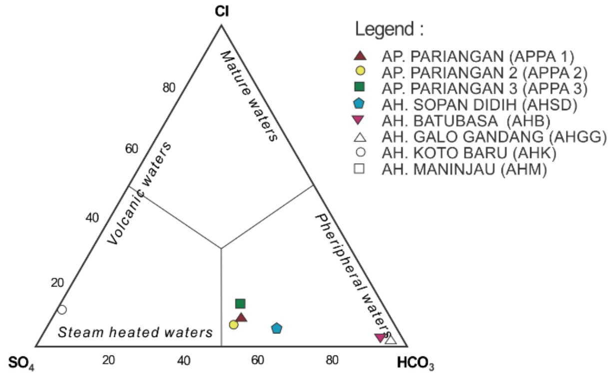

Figure 9. SO_4-Cl-HCO^3 diagram.

Based on the Na-K-Mg plotting diagram (Fig. 10), it shows that the entire Pariangan hot water sample is in the immature water zone, occur with the presence of carbonate sinter [15].

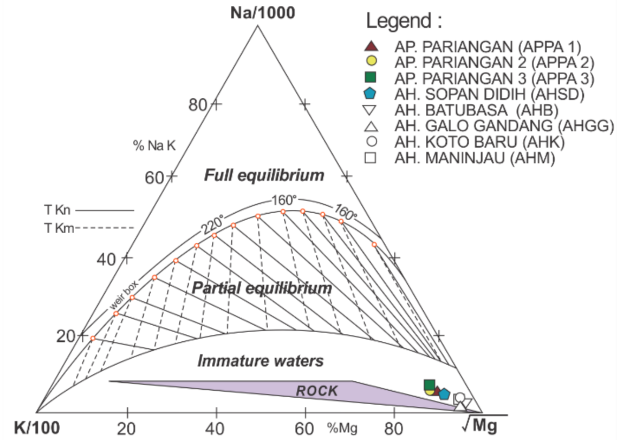

Figure 10. Na-K-Mg diagram.

Whereas the Cl-Li-B diagram (Fig. 11) shows that the overall Pariangan hot water sample have higher temperature than the manifestations in the study area.

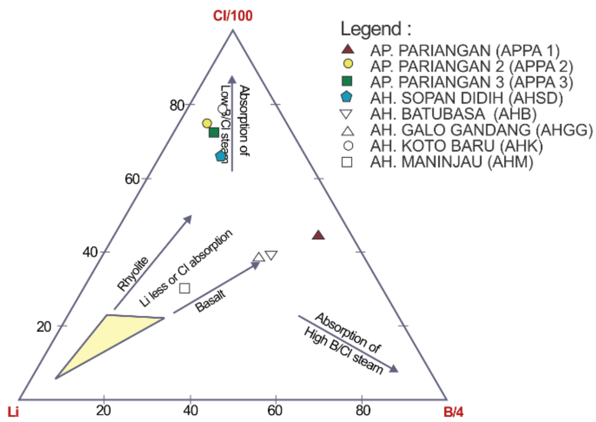

Figure 11. Cl-Li-B diagram.

Based on Oxygen Isotope 18 data, cold water is -7.86 ‰, warm water is -10.10%, while hot water is -9.55 - (-9.47) ‰. The isotope of Deuterium cold water is -57.10 ‰, warm water is -79.10%, while the hot water is -82.20 - (-81.80) ‰. Plotting the results of isotope analysis on the graphic δ D to δ18O graph (Fig. 12), the position of hot water and warm water is located to the right of the Meteoric Water Line (MWL) line, which is further away from the position of cold water, as an indication that the formation of hot springs and warm water associated with the interaction between hot fluid in the geothermal system with the rocks in its path.

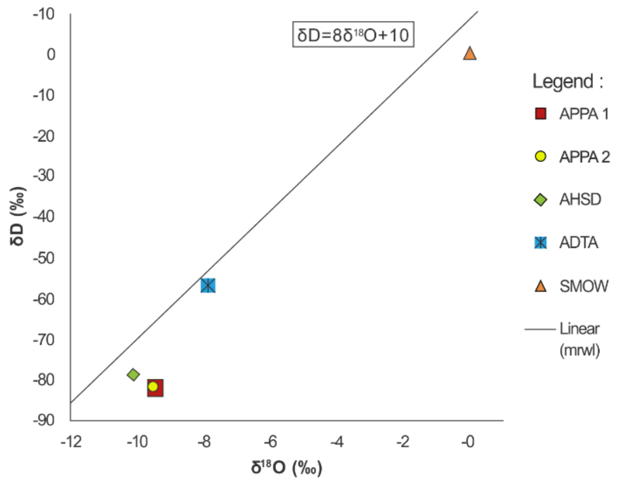

Figure 12. Isotop ^{18}O and deuterium diagram (Nurhadi, M. & Kusnadi. D).

E. Magnetotelluric

Magnetotelluric method have results of 2D resistivity modeling with the direction of the stretching points of the southwest – northeast (Fig. 13). In the second line geophysical measurement that passes through the manifestation of hot water. In the low resistivity layer <30 Ohm.m with a depth of about 1500 m with a thickness of about 500 - 1000 m as a cap rock with andesite lithology that have altered into clay minerals. While in the medium type layer (30 - 200 Ohm.m) with a depth of about 2000 m with a thickness of about 1000 m as a geothermal reservoir with quartz sandstone or limestone lithology.

In addition there is a geological structure in the northwest-southeast direction in accordance with the regional structure of the study area that controls the manifestation of geothermal energy out to the surface of the earth. The geological structure was recognized through the discontinuity of rock type resistivity as fault zones or fractures.

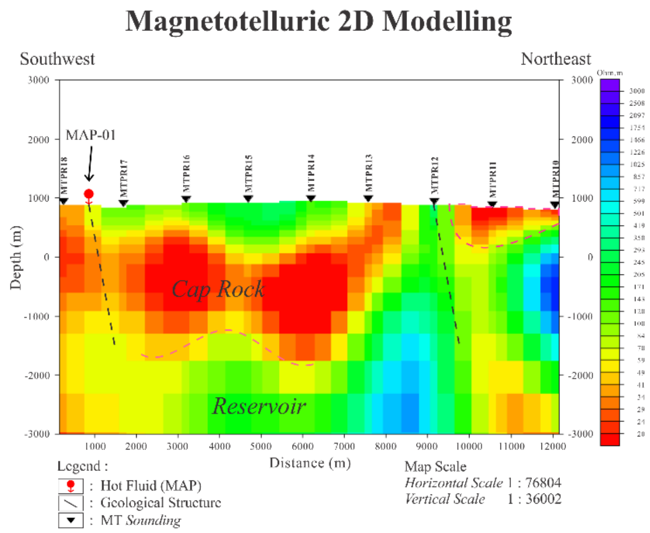

Figure 13. Magnetotelluric 2D modelling.

IV. Conclusions

Based on the result of the analysis with remote sensing, geochemistry, and magnetotelluric to identify geothermal potential in West Sumatera are interpreted that volcanic rocks such as tuff, lapilli, lava, and andesite with northwest-southeast geological structures dominate the lithology. Then, surface temperature anomaly identify by high temperature and associated with geothermal system is in the southern part of the research's location. Beside that, remote sensing with Lineament Density Analysis (LDA) has a southeast-northwest direction with an average length of 2280.14 m. The anomaly with the prospect permeability as a fluid pathway to produce a geothermal system have ranges from 2.05 to 4.76% per km^2. The geochemical data showed that the formation of hot springs and warm water associated with the interaction between hot fluid in the geothermal system with the rocks in southeast-northwest direction path. Subsequently, magnetotelluric data showed andesite lithology altered into clay minerals as a cap rock with a depth of about 1500 m with a thickness of about 500 - 1000 m and quartz sandstone or limestone lithology as a geothermal reservoir with a depth of about 2000 m with a thickness of about 1000 m.

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References

[1] D. Y. W. S. Pambudi, M. Sakur, K. Ismail, I Fajri, Dwiyono, L D Setijadji (2014). Delineasi Daerah Prospek Panas Bumi berdasarkan Kelurusan Citra

Landsat dan Digital Elevation Model (DEM) Daerah Gunung Lawu Provinsi Jawa Tengah dan Jawa Timur. Pros. Sem. Nas. Kebumian Ke-7, Yogyakarta: Universitas Gadjah Mada, pp. 438–446.

[2] Kementerian Energi dan Sumber Daya Mineral, "Potensi Panas Bumi Indonesia Jilid 1". Jakarta, Indonesia: Direktorat Panas Bumi Direktorat Jenderal Energi Baru, Terbarukan dan Konservasi Energi Kementerian Energi dan Sumber Daya Mineral, 2017, 164.

[3] M. Kholid and M. Nurhadi. (2011). Survei Gaya Berat dan Audio Magnetotellurik (AMT) Daerah Panas Bumi Pariangan, Kabupaten Tanah Datar, Provinsi Sumatera Barat. Kelompok Program Penelitian Panas Bumi : Pusat Sumber Daya Geologi.

[4] A. Sugianto, and A. Munandar. (2010). Survey Magnetotellurik Daerah Panas Bumi Gunung Lawu Jawa Tengah-Jawa Timur, Hasil Kegiatan Pusat Sumber Daya Geologi Bagian Kelompok Program Penyelidikan Panas Bumi,

[5] D. Jeevalakshmi, S. N. Reddy, B. Manikiam. (2017). Land Surface Temperature Retrieval from LANDSAT data using Emissivity Estimation. International Journal of Applied Engineering Research Volume 12, Number 20.

[6] G. B. Kim, J. Y. Lee, K.K. Lee. (2004). Contruction of Lineament Maps Related to Groundwater Occurrence with ArcView and AvenueTM scripts. Computers and Geosciences, Elsevier, Volume 30, Issues 9-10.

[7] G. Jordan, and B. Schott. (2005) Application of Wavelet Analysis to the Study of Spatial Pattern of Morphotectonic Lineaments in Digital Terrain Models : Remote Sensing of Environment. A Case Study, Elsevier, 31-38.

[8] L. Cagniard. (1953). Basic Theory Of The Magnetotelluric Method, Geophysics, 8, 605-635.

[9] W. M. Telford, L. P. Geldart, and R.E. Sherrif. (1990). Applied geophysics, Cambridge University Press.

[10] G. V. Keller, and A. A. Kaufman (1981). The Magnetotelluric Sounding Method, Elsevier Scientic Publishing Company.

[11] Tim Eksplorasi PSDMBP. (2014). Eksplorasi Terpadu Magnetotellurik, Bandung, Pusat Sumber Daya Minral Batubara dan Panas Bumi.

[12] Silitonga, P.H dan Kastowo. 1996. Peta Geologi Lembar Solok, Sumatera Skala 1:250.000. Pusat Penelitian dan Pengembangan Geologi. Bandung.

[13] Agus Solihin, dkk. (1992). Laporan Pemetaan Gunung Marapi, Sumatera Barat. Direktorat Vulkanologi. Bandung.

[14] M. Nurhadi, and D. Kusnadi. (2015). Survei Terpadu Geologi Daerah Panas Bumi Pariangan, Kabupaten Tanah Datar, Provinsi Sumatera Barat. Kelompok Program Penelitian Panas Bumi : Pusat Sumber Daya Geologi.

[15] L. Raybach, and L. J. P. Muffler. (1981). Geothermal Systems, Principles and case Histories. John Willey and Sons. Chichester.