IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Fault Fracture Density Analysis to Determine Geothermal Prospect Area in Dolok Marawa

[1]Batistuta Sihotang, [1]Agus Didit Haryanto, [1]Johanes Hutabarat, [1]Dewi Gentana

[1]Faculty of Geological Engineering, Padjadjaran University, Indonesia

Abstract: The Dolok Marawa study area is administratively located in Silou Kahean District, Simalungun Regency, and North Sumatra Province, selected as an area that is estimated to have geothermal potential that appears to the surface related to the development of geological structures caused by the activity of the Sumatra Fault system. This study aims to estimate the geothermal prospect area through the method; remote sensing of geological structure lineaments, fault fracture density (FFD) and application of 3D modeling micromine software which is correlated to the distribution of surface geothermal manifestations. The results of remote sensing analysis on DEMNAS images and Indonesia's Topographic Map at a scale of 1:50.000, there are two main patterns of geological lineament trending northeast- southwest (NE-SW) is interpreted to be influenced by the Sigayung-Gayung Fault (N 40°-60° E), and the geological structure lineaments trending northwest-southeast (NW-SE) is interpreted to be influenced by the Bahtopu Fault and the Bahbotala Fault (N 320°-325° E). The results of the fault fracture density (FFD) analysis show that there are five lineament density areas; (a) very low (FFD value: 0-0.5 km/km^2), (b) low (FFD value: 0.5-1.5 km/km^2), (c) moderate (FFD value: 1.5 -2.5 km/km^2), (d) high (FFD value: 2.5-3 km/km^2) (e) very high (FFD value: 3-3.38 km/km^2. Areas that have high to very high FFD values form a permeable zone in the Toba pyroclastic rock unit (Qjt) which contributes to the appearance or distribution of geothermal manifestations on the surface. Furthermore, the permeable zone through 3D micromine software modeling which is correlated to the distribution of geothermal surface manifestations shows clearly that the area which has high to very high lineament densities describing the pattern of geological structures on the surface which is localized as a geothermal prospect area. The geothermal prospect area is approximately 13.7km^2, located in the area around the center of Dolok Marawa that lies in the northeastern part of Bukit Bahtopu.

Key words- Dolok Marawa, Fault and Fracture Density, Micromine, Geothermal Manifestation

I. INTRODUCTION

Geothermal energy is clean energy that is sustainable which is being developed in Indonesia. The island of Sumatra is not separated from the volcanic arc due to subduction between the oceanic plate and the continental plate (Katili, 1975). The formation of the volcanic arc provides great potential for geothermal development in Indonesia (Figure 1).

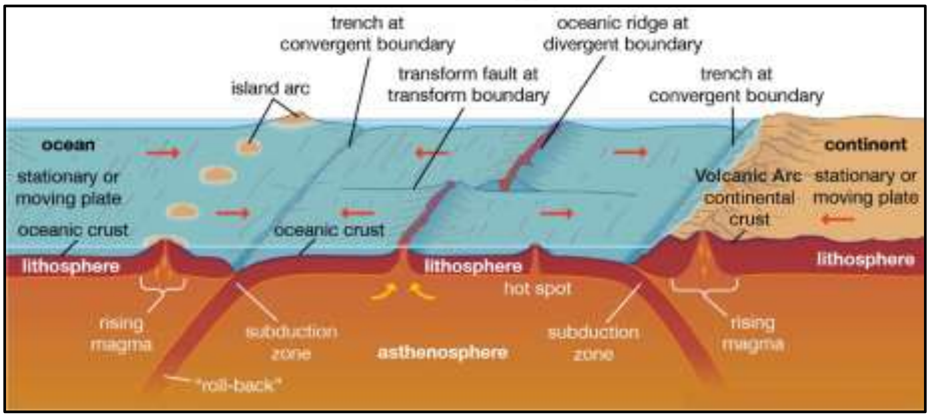

Figure 1. Plate subduction forming a volcanic arc (Rafferty, 2011)

Energy demand in Indonesia significantly causes the utilization of geothermal energy to increase. Indonesia has huge reserves of geothermal energy reaching 23.9 Giga Watt (GW) which is expected to be utilized to meet energy needs and also to increase community economic activities. Geothermal energy utilization is 8% which is equivalent to 2130 MW (Table 1). Utilization of geothermal energy is expected to reach 23% in 2025 (Directorate General of New Renewable Energy and Energy Conservation or EBTKE, 2020).

Table 1. Distribution of installed capacity from geothermal energy utilization in Indonesia (EBTKE, 2020)

No	Island	Location Number	Resources (MW)					Total	Installed Capacity (MW)
			Speculative	Hypothetical	Reserves				
					Possible	Expected	Proven		
1	Sumatra	101	2276	1557	3735	1040,7	1070,3	9679	744,4
2	Java	73	1265	1190	3414	418	1820	8107	1253,8
3	Bali	6	70	21	104	110	30	335	0
4	Nusa Tenggara	31	190	148	892	121	12,5	1363,5	12,5
5	Kalimantan	14	151	18	13	0	0	182	0
6	Sulawesi	90	1365	362	1041	180	120	3068	120
7	Maluku	33	560	91	497	6	2	1156	0
8	Papua	3	75	0	0	0	0	75	0
	Total	351	5952	3387	9696	1875,7	3054,8	23965,5	2130,7
					14626,5				
			23965,5						

The Dolok Marawa area is administratively located in Silou Kahean District, Simalungun Regency, North Sumatra Province is one of the locations in Indonesia which is estimated to have geothermal potential. Geothermal potential can be identified from the geothermal manifestations that appear on the surface (Hochstein and Browne, 2000). Indications of the presence of geothermal potential in Dolok Marawa area are the appearance of hot springs and travertine on the fault that has northwest-southeast directions (Sundhoro et al., 2006). The formation of geological structures that form fault zones or fractures in rocks is an indication of the existence of a permeability zone which is an important aspect in geothermal exploration.

The existence of the permeable zone is a pathway for the geothermal fluid migration process from the reservoir to the surface (Soengkono, 1999). Geological lineaments in the form of valleys, rivers, and ridges, are estimated to be formed by fault activity (Chemong and Chenrai, 2013). Analysis of geological structures in this study is done through lineament density, where areas that have high fracture intensity, density values form a weak zone or permeability zone in the rock (Gentana, 2018). So, the existence of geothermal resources is usually indicated by the appearances of geothermal surface manifestations as a result of heat dissemination from the subsurface and the geothermal fluid flow to the surface through the rock fractures. In the study area, there are seven hot spring locations that have chloride, bicarbonate and bicarbonate types of water (Iim, et all, 2006). The appearance of hot springs in the Toba pyroclastic fall volcanic rock is associated with several geological structures. This study aims to evaluate the main pattern of geological lineament related to fracture density, and rock permeability, especially around the appearance of surface geothermal manifestations, which indicate the geothermal prospect area in the Dolok Marawa area.

II. LITERATURE REVIEW

2.1 Regional Tectonics of Sumatra

The subduction formed on Sumatra Island, namely between the Indo-Australian plate and the Eurasian plate in the Pleistocene - Pliocene, is an oblique subduction with an angle of N 20° E (Darman and Sidi, 2000). The subduction causes the Indo-Australian plate to move relatively North-Northeast under the relatively stationary Eurasian plate. The resultant two forces between the vertical (down) subduction movement and the horizontal movement cause the oblique movement.

The result of oblique subduction produces volcanic pathways, sedimentary basins and horizontal fault systems. The Sumatran fault is a fault formed as a result of a series of structures formed by tectonic patterns with a Northwest-Southeast (NW-SE) pattern. The result of the shift produces a weak zone that allows magma to escape in the volcanism activity that produces the Barisan mountain range. At the beginning of the Tertiary there was a transtension stress system that caused the formation of sedimentary basins such as the North Sumatra Basin (Haryanto, 2011). The study area is located in the eastern part of the Sumatra Fault, approximately 60 km from Lake Toba (Figure 2).

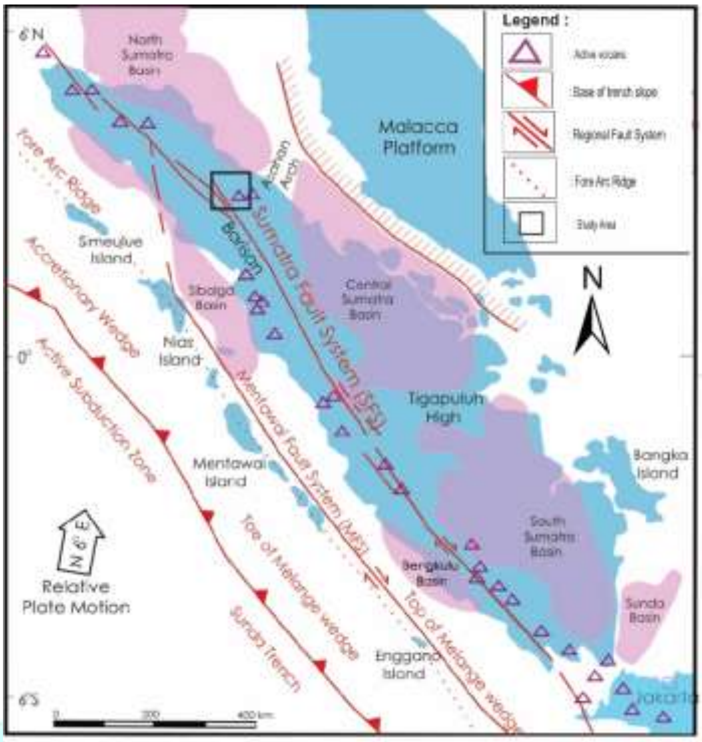

Figure 2. The regional tectonic framework of the Sumatra Basin (Darman and Sidi, 2000)

2.2 Regional Geology

The rocks that produce the Dolok Marawa area are dominated by volcanic rocks, pyroclastic, limestones and altered rocks (travertine). In the Dolok Marawa area there are geothermal manifestations in the form of hot springs scattered around the Tinggi Raja hills in the Toba pyroclastic fall (Qjt) rock unit, where at the location of the hot springs there are also solid travertine deposits (Figure 3).

Dolok Marawa has an elevation ranging from 176–1020 meters above sea level forms steep and undulating hill morphologies occupies about 70% of the research area. Dolok Marawa Peak as Bahtopu Hill composed by the Bahtopu lava unit. The plain morphology occupies 15% of the study area which is composed of Toba Pyroclastic Flow rock units and the remaining 75% is undulating hills (low-high hills) composed of Toba Pyroclastic Fall rock units.

The geological structure of the study area is influenced by the presence of subduction plate tectonics trending northwest-southeast (NW-SE), such as between the Indo-Australian plate which subducts the Eurasian plate which causes the Sumatran Fault. The Bahtopu fault and the Bahbohtala fault are a type of dip slip fault. In the western block, the Bahtopu fault rises relative to the eastern block. Then the eastern block of the Bahbotala Fault rises relative to the western block (east block of the Bahtopu Fault) whereas the two faults form a graben.

The Bahtopu fault and the Bahbohtala fault are thought to be geological structures that contribute to the appearance of hot springs in the study area. The fault has a northwest-southeast (NW-SE) direction (Iim, et al, 2006). In general, the geothermal system in the Sumatra area is a volcanic-tectonic geothermal system where the volcanic cone (Bukit Bahtopu) is associated with graben (Kasbani, 2009). 3D micromine software modeling on geological lineaments provide numerical values of azimuth N270°E and N310°E with slope angles of 30° to 65°, contribute to the geothermal manifestation appearance in the southern part of Sumatra form large depression area (Gentana, et all). Then, from the geological cross section A-B with a northeast-southwest trending (NE-SW) which is plotted on a geological map figure 4, it shows that the geothermal manifestation area is in a graben bounded by the Bahtopu fault on the left and the Bahbotala fault on the right (Figure 4).

Manifestations of hot springs in the Dolok Marawa area have chloride and bicarbonate hot springs with surface temperatures between 37.4° – 65.6°C. Based on SiO_2 geothermometer calculations, the hot springs on the surface produce reservoir temperature estimates ranging from 121° -128°C, it shows that the reservoir system is in the medium enthalpy category (Directorate General of New Renewable Energy and Energy Conservation, 2017).

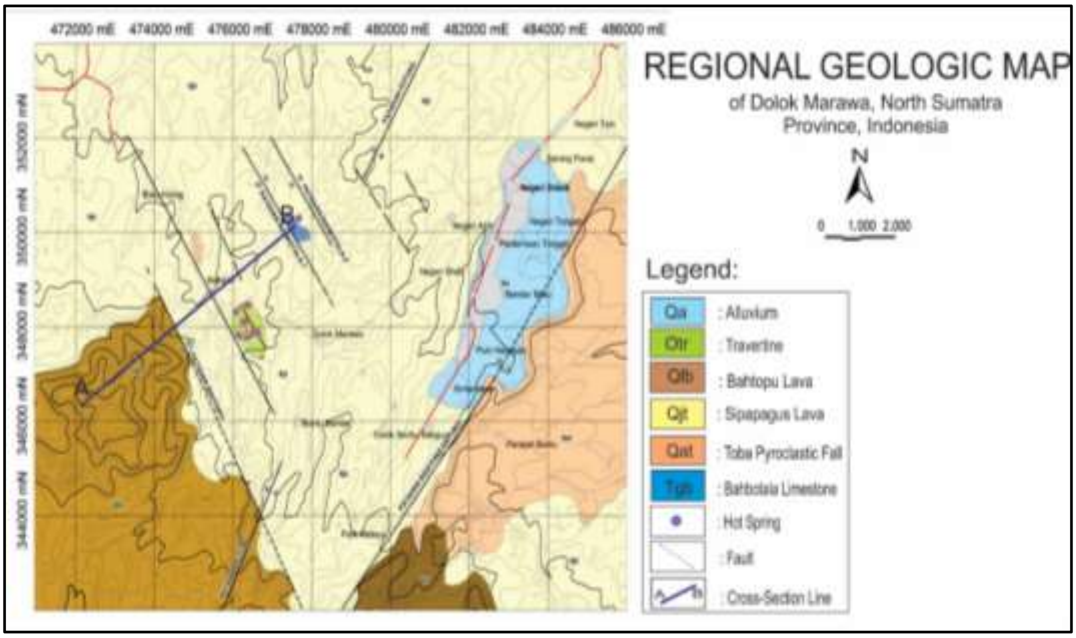

Figure 3. Regional geological map of the Dolok Marawa geothermal area
(Iim, et al., 2006 modification of the Geological Map of the Medan Sheet by Cameron et al., 1982)

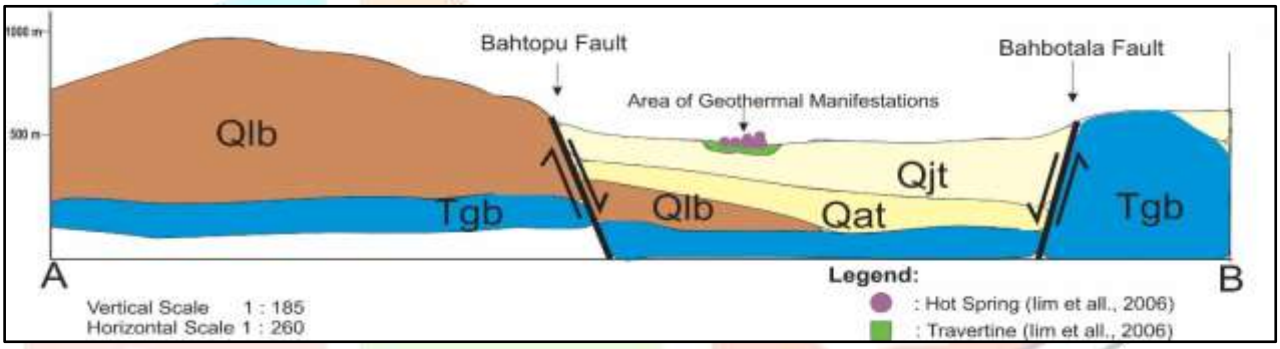

Figure 4. The geological cross-section of the Bahtopu fault and the Bahbotala Fault to form a graben, manifestations in the study area are fault areas that form graben (modified from Iim, et al., 2006)

III. METHOD

The research object of this study, the geological lineament pattern and fracture density using data obtained from the Digital Elevation Model National (DEMNAS) image, Indonesia's Topographic Map, and previous researcher which related to the location of presence of geothermal manifestations. The pattern of geological lineament is carried out through geospatial remote sensing methods. Determination of the permeable zone is identified through fault fracture density (FFD) analysis. The fracture density intensity is expressed as the total straight length per unit area. In the calculation, a grid system with a size of 1x1km^2 is used as the area to calculate the lineaments, so that the midpoint of each grid has straightness length data per unit area or km^2. The Micromine software is used to process all data both of DEMNAS image and topographical map to delineate the geothermal prospective areas based on a combination of the permeability map and the presence of surface geothermal manifestations.

IV. RESULTS AND DISCUSSION

4.1 Analysis of Geological Structural Patterns

Straightness interpretation based on DEMNAS image with radiating azimuth; 0°, 45°, 90°, and 135° as well as the same altitude, which is 45° which are then combined (overlays) of the four azimuths to obtain images that represent the actual topography of the study area (Figure 5).

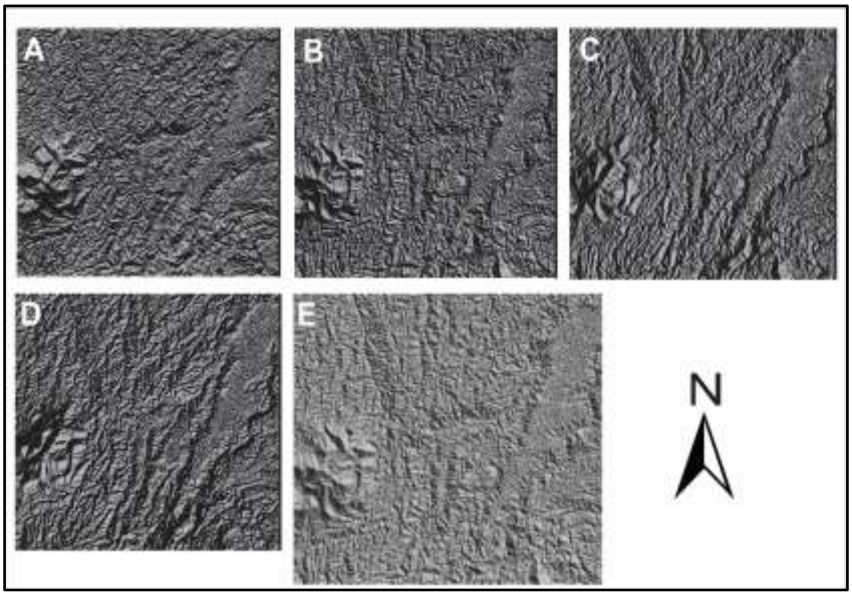

Figure 5. A. Image with 0° azimuth; B. Image with 45° azimuth; C. Image with 90° azimuth; D. Iimage with an azimuth of 135°, and E. The result of overlaying the four images

The results of the drawing of geological lineaments in the study area have a total lineament of 741 lines shows the direction of the main pattern of geological lineament is northeast-southwest (NE-SW) and northwest-southeast (NW-SE), whereas geological lineaments are interpreted as faults. Geological lineaments which are depicted on the rose diagram in the map of geological lineament patters shows there are relatively have two main patterns of geological lineaments that contribute to the presence of surface geothermal manifestations in the study area (Figure 6), namely:

a. Structural Patterns of Northeast-Southwest (NE-SW)
The structural pattern trending northeast-southwest (NE-SW) is interpreted to be influenced by the Sigayung-Gayung fault (N 40°-60° E), and the young Putung fault in the vicinity of Bukit Bahptopu, Silokahean and Rayakahean.

b. Structural Patterns of Northwest-Southeast (NW-SE)
Trends Structural patterns trending with northwest-southeast (NW-SE) is interpreted to be influenced by faults that have a direction parallel to the Sumatran fault such as Bahtopu fault and the Bahbotala fault (N 320°-325° E) occupies around in the northern part of Bukit Bahtopu, Bahoan and Batu Holing areas.

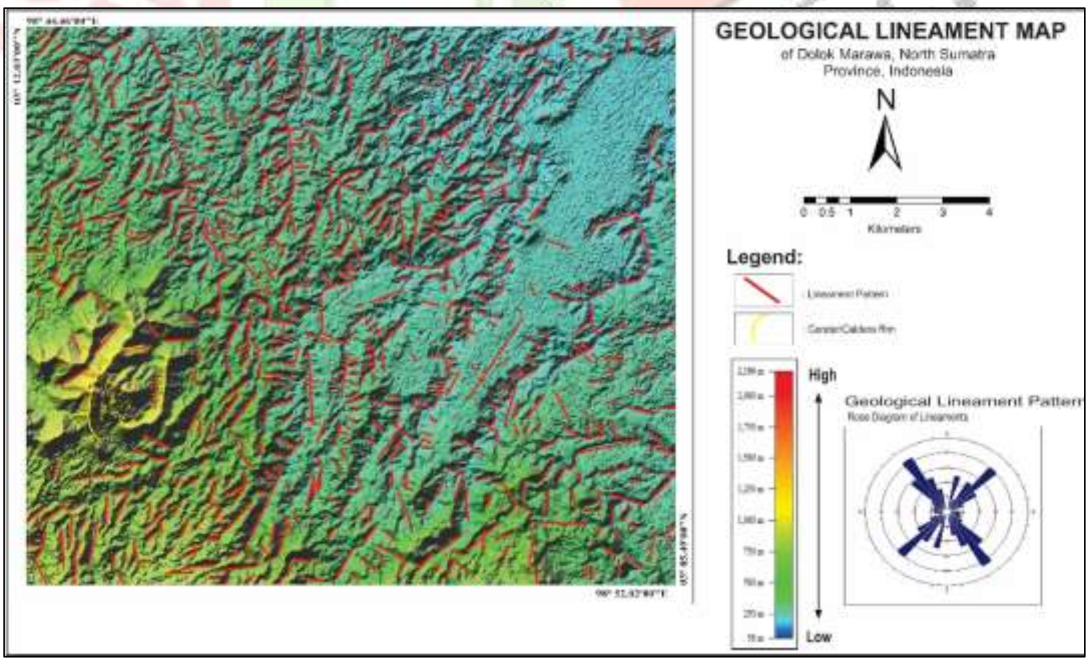

Figure 6. Map of geological lineaments based on overlays of several light azimuths on DEMNAS image which is plotted in the rosette diagram shows that the study area have the main pattern of geological structures or faults trending northeast-southwest (NE-SW)

Geothermal manifestations in the study area appear at the edges and intersections of geological lineaments which associate with the main pattern of geological lineaments that have trending northeast-southwest (NE-SW) and northwest-southeast (NW-SE) directions (Figure 7). Therefore, the distribution of geothermal manifestations in the study area is influenced by the development of geological structures that have two main lineament patterns. In addition, in the southwestern part of the study area, there are circular structures related with crater or caldera remnants that indicate past volcanic activity.

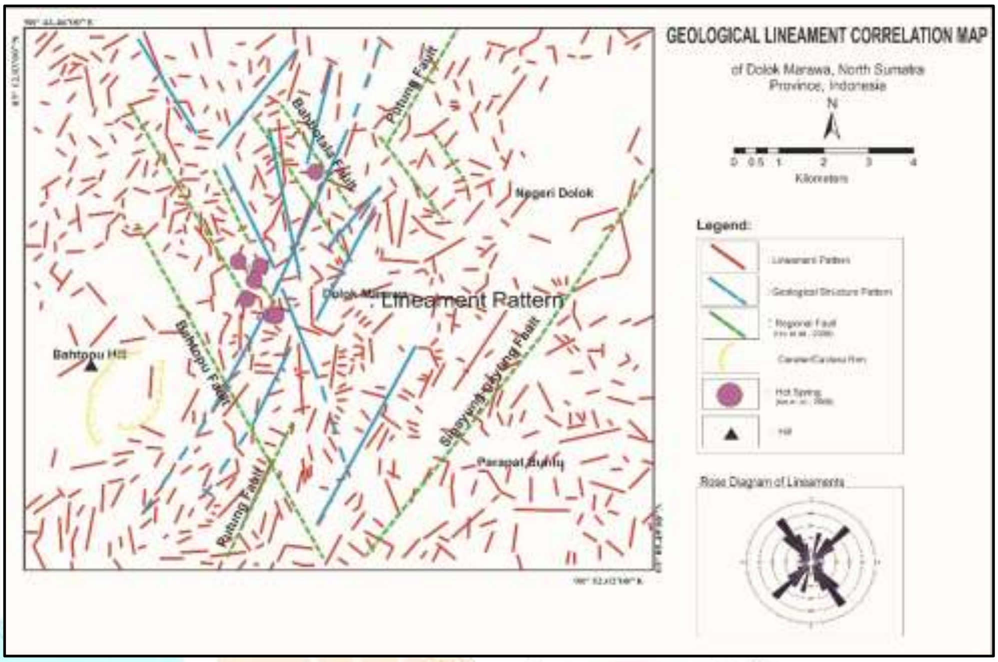

Figure 7. Development of geological structures in the study area on the distribution of geothermal manifestations shows a relatively similar pattern to regional faults

4.2 Permeability Zone

Permeability zones are obtained based on the results of the analysis of geological structure lineaments which are then calculated for the density of the structure in an area of 1 km^2. The results of the structural density calculation show that the fracture density varies from very low to very high with FFD values ranging from 0 – 3.38 km/km^2 (Figure 8).

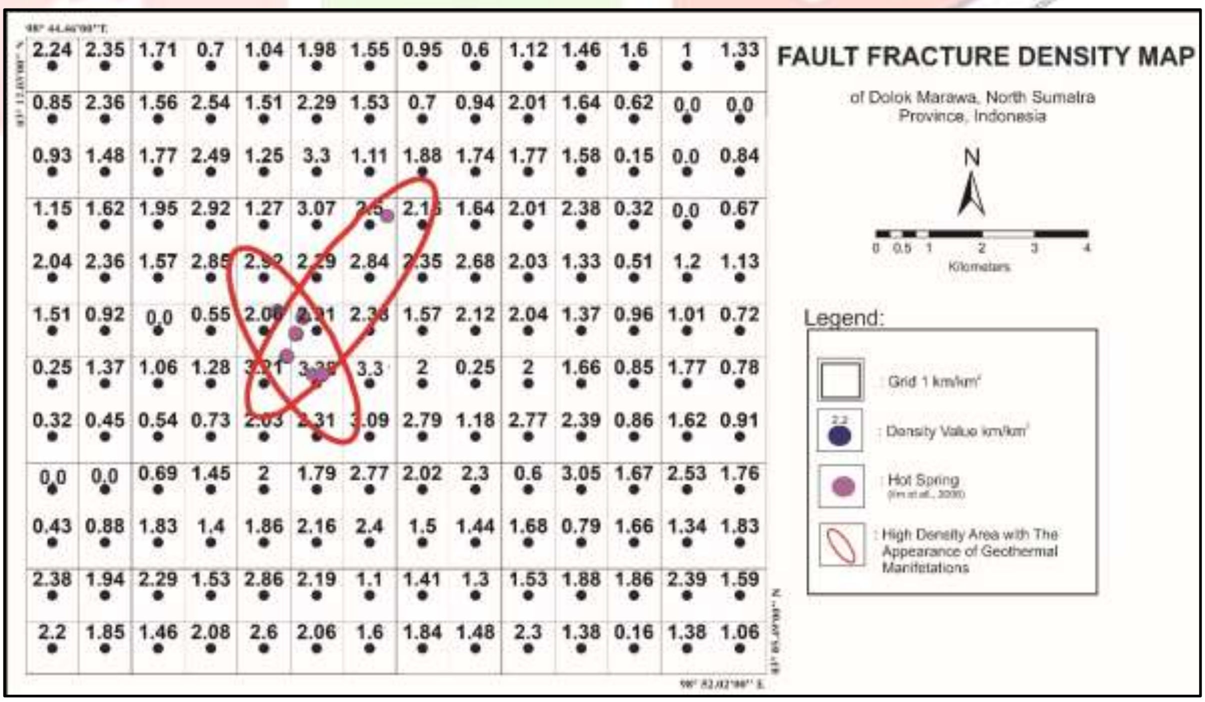

Figure 8. Fracture or fracture density level map for each 1 km^2 grid showing distribution of geothermal manifestations, namely hot springs are located in areas that have high fracture or fracture density values

a. **Density Value 0-0.5 km/km^2 Very Low Category**

Density values of 0-0.5 km/km^2 in the very low category are shown in dark green. It is found in Bahtopu lava units (Qlb), Alluvium (Qa), Toba pyroclastic flows (Qat) and Toba pyroclastic falls (Qjt). All of these rock units occupy the peak area of Bahtopu Hill and the alluvium unit is the plains of the Dolok State area which is not influenced by geological structures.

b. Density Value 0.5-1.5 km/km^2 Low Category

Density values of 0.5-1.5 km/km^2 in the low category are shown in light green. It is found in Bahtopu lava units (Qlb), alluvium (Qa), Toba pyroclastic flows (Qat) and Toba pyroclastic falls (Qjt). All of these rock units occupy the peak area of Bukit Bahtopu, Negeri Dolok (area of alluvium units in the form of plains) and Dolok Sileou. The area is interpreted as an area that is slightly influenced by geological structures.

c. Density Value 1.5-2.5 km/km^2 Medium Category

The density value of 1.5-2.5 km/km^2 is a medium category shown in yellow. It is found in Bahtopu lava units (Qlb), Sipapagus lava (Qls), Toba pyroclastic flows (Qat) and Toba pyroclastic falls (Qjt). All of these rock units occupy the Siloukahean, Rayakahean and Dolok Seribubangun areas. This area is interpreted as an area that is influenced by moderate (not very intensive) geological structures of the Sigayung-gayung Fault and the Bahtopu Fault.

d. Density Value 2.5-3 km/km^2 High Category

The density value of 2.5-3 km/km^2 is the high category shown by the orange color. It is found in the Bahtopu lava unit (Qlb) and the Toba pyroclastic fall (Qjt). All of these rock units occupy the Bahoan and Batuholing areas. This area is interpreted as an area that is intensively influenced by geological structures from the Putung Fault, Bahbohtala Fault and Bahtopu Fault.

e. Density Value 3-3.38 km/km^2 Very High Category

The density value of 3-3.38 km/km^2 is a very high category shown by the red color. Found in the Toba pyroclastic fall unit (Qjt). This area is interpreted as an area that is heavily influenced by geological structures that occupy the Bahoa area, and the center of Dolok Marawa which has been heavily affected by geological structures, namely the Bahbohtala Fault and the Bahtopu Fault. In this area, surface geothermal manifestations are found in the form of hot springs whose appearance follows the main pattern of lineaments trending northeast-southwest (NE-SW) which is relatively the same as the regional faults formed in the study area.

Overall density values from very low to very high which describe the density of fractures or faults in the study area are depicted on the permeability zone map (Figure 9)

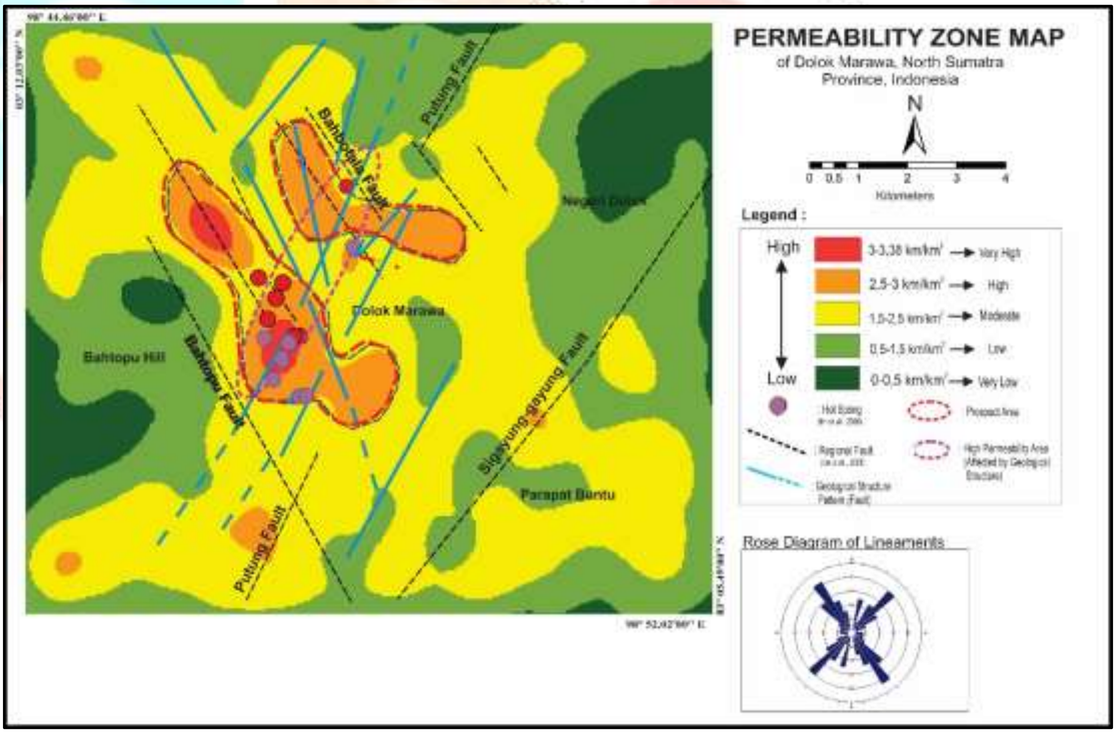

Figure 9. Map of the permeability zone of the Dolok Marawa area showing the appearance and distribution geothermal manifestations, namely hot springs are located in areas that have a high density level –very high. The lineament of the geological structure or fault shows a pattern that is trending northwest – southeast (NW-SE) and northeast – southwest (NE-SW), this is the same as the regional fault direction.

The higher the fault fracture density, the higher the permeability value. Fault fracture density analysis results show that the red and orange zones are areas with high to very high fracture densities (FFD value; 2.5-3.38 km/km^2). This expresses the area that has the highest level of permeability formed in the Toba pyroclastic rock unit (Qjt). In areas that have high to very high permeability levels where geothermal manifestations appear to the surface from a geothermal system below the surface (reservoir) are interpreted as prospect areas.

4.3 3D Modeling of Study Area

The geological lineament pattern in the study area which is interpreted as a fault plane forms a weak zone or permeability zone which is associated with the appearance of geothermal manifestations from the reservoir to the surface in the form of hot springs with travertine. Through 2D and 3D micromine software modeling the existence of geothermal manifestations is clearly seen that their appearance and distribution to the surface is facilitated by geological structures (faults) that develop in the study area.

The areas that have accumulated geological lineages (faults) are zones with a high level of permeability that can be a reservoir for fluid circulation in geothermal reservoirs. The circulation in question is that in the permeable zone the fluid can flow through a fault plane to the reservoir rock (in the recharge zone) and also to the surface as a geothermal manifestation. Based on the permeability zone map depicted by 2D modeling and 3D micromine software, it is correlated to the appearance or distribution of surface geothermal manifestations which is then drawn a line that localizes the area which is estimated to be a geothermal prospect area in the Dolok Marawa area which has an area of 13.7 km^2. This prospect area occupies the area around Dolok Marawa which is in the northeastern part of Bukit Bahtopu (Figure 10).

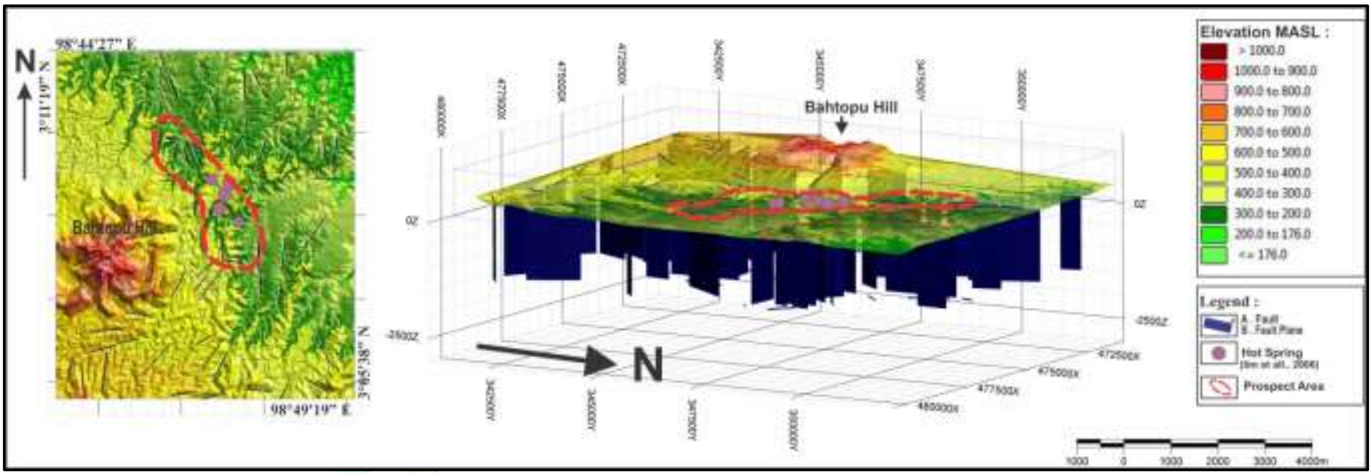

Figure 10. 2D & 3D models show the appearance of geothermal manifestations facilitated by geological structures in the form of faults that develop in the study area

V. CONCLUSION

Based on the results, it can be concluded that Dolok Marawa has two main patterns of geological structure trending northeast-southwest (NE-SW) and northwest-southeast (NW-SE) which is interpreted to be influenced by the Sigayung-Gayung Fault (N 40°-60° E) and by faults parallel to the Sumatran Fault such as the Bahtopu Fault and the Bahbotala Fault (N 320°-325° E). The results of the FFD analysis show that the distribution of surface geothermal manifestations, namely hot springs and travertines are located in an area that have fault fracture density values; 2.5-3.38 km/km^2 (high-very high category) occupying in the Toba Pyroclastic Fall lithology unit (Qjt). The density value of the geological structure indicates a high to very high permeability level in rocks which are permeable zones in a geothermal system. Based on the permeability map in areas that have high to very high fracture density values described through a 3D model of micromine software, then correlated with the distribution of surface geothermal manifestations, it is interpreted that the prospect area of 13.7 km^2 is located around Dolok Marawa, and in the eastern part of Bukit Bahtopu.

VI. ACKNOWLEDGMENT

Thank you to the Faculty of Geological Engineering, Padjadjaran University and all parties who have supported the creation and publication of this paper and for allowing the use of micromine software license.

REFERENCES

[1] Cameron, N.R., J.A. Apsden. D. Mc. Bridge. A. Djunuddin. 1982. Geology Map Sheet Medan, Sumatra. Publikasi P3G Bandung.
[2] Chemong C.A. and Chenrai P. 2013. Fracture Density Analysis in the Sai Yok Fault, Western Thailand and its Implications for Hydrological Exploration. Study Journal of Applied Sciences, 125-130
[3] Darman, Herman, and F. Hasan Sidi. 2000. An outline of the Geology of Indonesia. Jakarta. IAGI. 192p.
[4] Direktorat Panas Bumi, Ditjen EBTKE (Indonesia's Directorate General of New Renewable Energy and Energy Conservation). 2017. Indonesia's Geothermal Potential Volume I. Jakarta. EBTKE Indonesian Ministry of Energy and Mineral Resources
[5] EBTKE (Indonesia's Directorate General of New Renewable Energy and Energy Conservation). 2021. Government Finalizes Tampomas Geothermal Exploration Plan.https://ebtke.esdm.go.id/post/2021/03/05/2817/pemerintah.matangkan. rencana.eksplorasi.panas.bumi.tampomas (Accessed, at 03.00 PM, June 27 2021)
[6] Gentana, D., Sukiyah, E., Sulaksana, N., Yuningsih, E.T, Balia, L. 2017. Determination of Tanggamus Geothermal Prospect Area, Lampung Provinces Southern Part of Sumatra Based on Remote Sensing And 3D Micromine Software, FIG Workig Week 2017. Helsinki, Finlad, May 29 – June 2,2017
[7] Gentana, D. 2018. Geomorphic Index as a Basis for Neotectonic Characterization for Determining Geothermal Prospects in Mount Rendingan and Its Surroundings, Lampung. Dissertation. Faculty of Geological Engginering Padjadjaran University, Bandung
[8] Haryanto, I. 2011. Geological Structure in The Transitional Zone between The Bukit Barisan Volcanic Arc and The Back Arc Basin: Examples in North Sumatra. Bulletin of Scientific Contribution, Vol. 9, No. 1, April 2011: 8-16.
[9] Iim D., Setiadharma, H., Sundhoro H., Sulaeman B. 2006. Geological and Geochemical Investigations in The Dolok Marawa Geothermal Area, Simalungun Regency-North Sumatra. Proceding Pemaparan Hasil Kegiatan Lapangan Dan Non Lapangan Tahun 2006, Pusat Sumber Daya Geologi Bandung.

[10] Kasbani. 2009. Types of Geothermal Systems in Indonesia and Estimated Energy Potentital. Buletin Sumber Daya Geologi Vol. 4, No. 9

[11] Katili, J.A. 1975. Volcanism and Plate Tectonics in The Indonesian Island Arc. Tectonics Physics, 165-188 pp.

[12] Rafferty JP., (Eds). 2011. Plate Tectonics, Volcanoes, and Earthquakes. New York. Britannica Educational Publishing

[13] Rupa Bumi Indonesia Map Sheet 0619-32 Negeri Dolok, Digital Indonesia Geospatial Information Agency of The Republic of Indonesia (BIG), 1982 (Accessed, at 11.06 PM, June 30, 2021)

[14] Seamless Digital Elevation Model (DEM) dan Indonesian National Bathymetry 0619-32; https://tanahair.indonesia.go.id/demnas/#/ (Accessed, at 11.06 PM, June 30, 2021)

[15] Soengkono, S. 1999. Analysis of Digital Topographic Data for Exploration and Assessment of Geothermal System. Proceeding 21st New Zealand Geothermal Workshop (1999b)

[16] Sundhoro, H. Bakrun. Dendi S., Bambang S., dan Timor S., 2006. Integrated Geothermal Survey (Geology, Geochemistry, and Geophysics) Dolok Marawa Area, Simalungun Regency - Sumatera Utara. Proceeding Pemaparan Hasil Kegiatan Lapangan dan Non Lapangan Tahun 2006. Pusat Sumber Daya Geologi