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Geothermal System in Bonjol Geothermal Prospect, Pasaman Regency, West Sumatera, Indonesia

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ABSTRACT

Bonjol geothermal area is located at Bonjol district, Pasaman regency in Province of West Sumatera. Geothermal manifestations consist of neutral pH hot springs with temperature ranging from 49.7 to 87.9 ºC. Hot springs with the highest temperature are located at Limau river, Takis, and Kambahan, which is located in Sumatera depression zone. Takis hot spring is controlled by Takis fault, while Padang Baru hot spring is controlled by Padang Baru fault.

The hot waters are of chloride type, indicating hot water dominated reservoir. Geothermal system in this area is supposed to be associated to volcanic activities. The youngest volcanic is Binuang dome which is supposed as a heat source for the geothermal system of the area. Gravity data reveal a high anomaly which is interpreted as an intrusive body beneath Takis hot spring.

The reservoir temperature in the Bonjol area is estimated about 180ºC from water geothermometry and had moderate entalphy.

1. INTRODUCTION

Bonjol geothermal area is located at Bonjol district, Pasaman regency in Province of West Sumatera. Geographic position is between 100°8'51,72"-100°16'27,48" East Longituade and 0°3'46,08" North Latitude – 0°3'43,2" South Latitude, **(Fig 1).** The youngest volcanic is Binuang dome which is supposed as a heat source for the geothermal system of the area. Gravity data reveal a high anomaly which is interpreted as an intrusive body beneath Takis hot spring. The reservoir temperature in the Bonjol area is estimated about 180ºC from water geothermometry and grouped into moderate entalphy.

Archipelago of Indonesia resided in volcanic belt has potency to form geothermal energy.

Bonjol Geothermal area is one of districts which are included into magma arc and volcanic unfolding coast wise west Sumatera Island.

2. GEOTHERMAL RESOURCES

Geothermal manifestations spread over in center of Bonjol area predominated by appearance of hot springs in Padang Baru, Takis river, Limau river, and Kambahan river. Alteration rocks also are found around Blimbing village and in northwest part which has alteration fossil. Explanation for the geothermal manifestations in detail is as follows.

Figure 1: Location map of Bonjol Geothermal Prospect.

2.1 Hot Springs

2.1.1 Padang Baru Hot springs

Padang Baru hot springs emerge from sedimentary rock, which presents beneath alongside hamlet road (street boundary, in house yard and even within doors resident, some of hot springs are accommodated for bath). Temperature of hot springs is about ± 49.7°C, pH= 6.5, colorless, and there is sinter carbonate (travertine). Appearance of these hot springs is controlled by Padang Baru fault.

2.1.2 Takis River hot springs

Takis river hot springs emerge at Takis river, presenting with temperature about ± 87.9°C, pH= 6.9, colorless, and travertine deposit are found around hot springs. Appearance of these hot springs is controlled by Takis fault and the direction of form lineation of hot springs is south west - north east.

2.1.3 Limau River hot springs

These hot springs are located about 1 km east to Takis hot spring which emerges from alluvium Limau river, presenting with temperature ± 73.5°C, pH= 7.3, colorless. There are air bubbles and carbonate sinters (travertine). Similar to the Takis hot springs, appearance of the Limau hot spring is also controlled by the same geology structure namely Takis fault.

2.1.4 Kambahan hot springs

Kambahan hot springs emerge from Langkuik river in Kambahan village. Hot springs temperature is about 73,4°C, with pH= 7.5, colorless, and no travertine deposit.

As Takis river hot spring and Sungai Limau hot spring, the Kambahan hot springs are also controlled by Takis fault.

2.2 Alteration rock

Alteration rocks are formed by hydrothermal influence which is found in northwest Bonjol geothermal prospect, north part of Bukit Gajah, around group of Takis hot springs, and west slope part of Bukit Malintang (gold mining area). The rock outcrop has color of white, grey, a few yellow-brown and has clay mineral dominance and predominating pyrites minerals with very strong alteration intensity. Based on the analysis of PIMA, mineralogy is as follows: montmorillonite, halosit, muscovite, paragonite, illite, and teflon.

3. GEOTHERMAL CHARACTERISTICS

To know the characteristics and the type of hot water from data of chemical composition, triangle diagram of Cl - SO_4 - HCO_3, Na-K-Mg, and Cl-Li-B was used (Giggenbach, 1988).

Based on **Fig 2**, 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 SO_4 and HCO_3, 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).

In the triangle diagram of Na-K-Mg (**Fig 3**), 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 180°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.

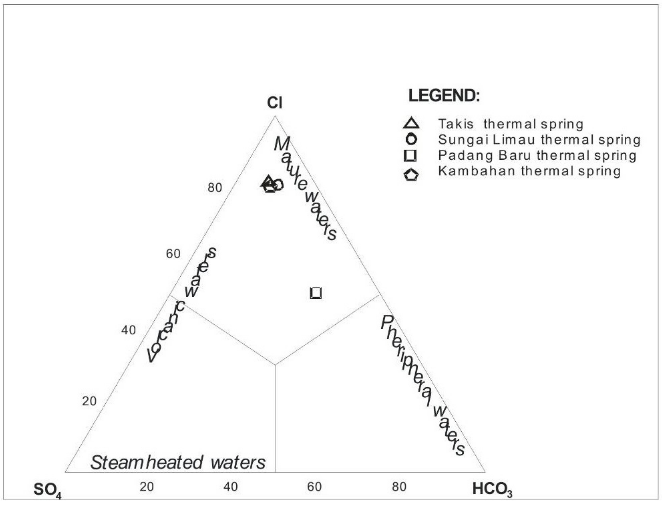

Figure 2: Cl-SO_4-HCO_3 diagram of Bonjol geothermal area.

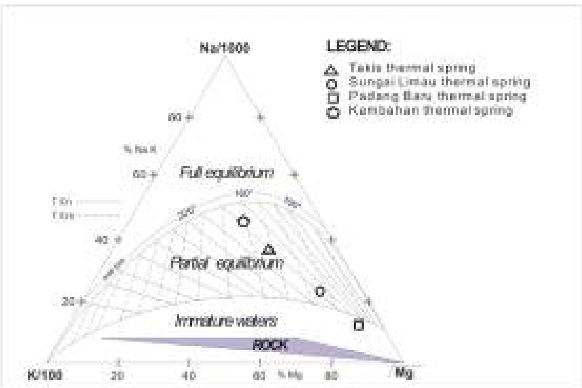

Figure 3: Na, K, Mg diagram of Bonjol geothermal area.

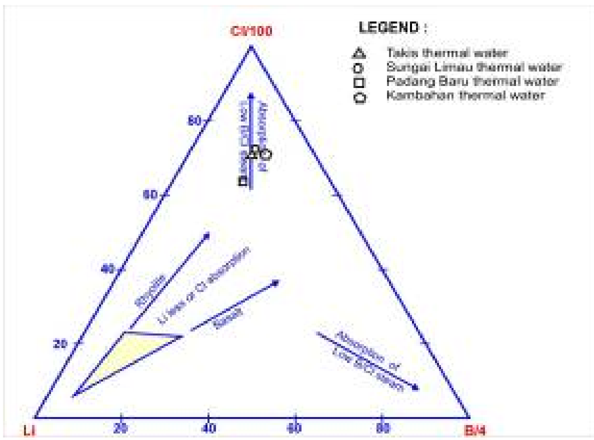

Figure 4: Cl, Li, B diagram of Bonjol geothermal area.

On Cl, Li, B (**Fig 4**) 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 (^{18}O *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.

4. GEOLOGY

Bonjol morphology predominated by structured precipitous finite medium with caster hilliness of young and old volcanic as well as sediment Sihapas Formation, which occupied almost all of the survey area (± 90 %), except in center depression zone loaded by lake sedimentary rock.

The eldest rock in Bonjol area is sedimentary rock in Sihapas Formation of Tertiary age, occuping north-east division. Other sedimentary rock is lake deposit occupying center Bonjol area of depression zone. While volcanic rock was found in the investigation district, some was estimated Tertiary age (Miocene) like product Bukit Malintang and set of stripper lava rock. Young volcanic rock occupies in west part, north part, and south part of the survey area. Based on age dating (fission track), lava Bukit Binuang is 1,3 ± 0,1 million years (Plistocene). The Bukit Binuang is estimated as volcanic taper which is young forming lava arch (lava dome) with Andesite augite. Alluvium deposit is set of young rock in the investigation district. Processing is still taking place until now (**Fig.5**).

5. GEOPHYSICS

5.1 Magnetic

Total isomagnetics map varied between - 1200 nT and 1450 nT and was divided into 4 parts as follows. Values between - 1200 finite nT and - 250 nT indicated alteration rock, either caused by sewer structures or caused by intrusion effect and mineralization process. Values between - 250 nT and 150 nT implied alluvial, sediment, pyroclastic and lava rock. Values (> 150 nT to 650 nT) and values (> 650 nT to 1450 nT) indicated the predomination by fresh andesite rock **(Fig.6)**.

Based on the results of magnetic survey, geothermal prospect in Bonjol area is located in north side related to manifestation Takis and Limau, while second prospect resided in southeast that is around manifestasion Padang Baru.

5.2 Gravity

A residual anomaly map is obtained by subtracting the regional map from the Bouguer anomaly map. The Residual anomaly with regional anomaly is local gravity anomaly. Anomaly map rest is response from rock under equal amplitude surface that is relative skin-deep. Based on the contrast, pulled lineation of contour is qualitatively interpreted as fault in depth.

Residual anomaly map of showing high anomaly zone (3-10 mgals) is residing around Takis river hot spring which shows that anomaly possibility generated by sewer structures. There is piquancy from the high anomaly zone, is this high zone generated by rock block with density that is higher than its surrounding or probably it is the body of intrusive rock ? The intrusive rock is younger than its surrounding. The intrusive rock is supposed to be heat source in survey area **(Fig.7)**.

5.3 Resistivity and Head-On

The map of apparent resistivity with AB/2=250 m **(Fig.8)** shows that low resistivity (<15 Ohm-m) distributes around hot springs of Limau river and Takis river with spread correction in north west-south east. Furthermore, AB/2=500, AB/2=800, and AB/2=1000 m show that low resistivity has wider area that is probably caused by hydrothermal alteration or related to clay stone from sedimentary rock closing over some of Bonjol area. High apparent resistivity (>250 Ohm-m) of AB/2=1000 m shows around Bukit Bituang compared to AB/2=800 m (**Fig.9**).

Based on Head-on results, there is one big structure controlling appearance of Padang Baru hot spring with dip fastigiated straight in north west-south east.

6. GEOTHERMAL SYSTEM

6.1 Heat Source

Source of temperature (heat source) is a principal component in a geothermal system, and there are some formations of geology which are able to become heat sources, firstly in the form of rest magma that associated with young volcano cones, both poisons in the form of young intrusive rock body.

In geology there are some areas in enabling Bonjol district to become heat source, that is Bukit Binuang which is 1.3 ± 01 million years age (Pleistocene) with rock type of andesite lavas.

6.2 Reservoir

Geothermal reservoir layer based on the definition is potting below (under surface having the character of den and powered passed to fluid, keep fluid hot and has temperature and pressure from geothermal system.

Geophysicist investigation, especially with electrical method (Schlumberger array), can not indicate of depth of reservoir layer, but the reservoir is estimated have depth > 1000 meter with resistivity value of 50 - 150 Ohm-m correlated with reservoir rock.

6.3 Cap Rock

Cap rock does not pass water or is impermeable so that hydrothermal fluid in reservoir layer detained below. Cap rock layer is in depth around 500 m to 800 m, with resistivity value around 10 - 15 ohm-meters.

Based on component of geothermal system, the geothermal system at Bonjol area spread over alongside graben structure which is part of Sumatra fault system (**Fig.10**).

7. CONCLUSION

Geothermal system in Sumatra generally relates to activity of volcano andesitis riolitis which is caused by source of magma having the character of acid and thicker. Geothermic systems in Bonjol does not get out of geothermic systems Sumatera Island which generally controlled by system fault regional related to Sumatra fault systems.

Magmatic process existed in narrower Sumatera Island if compared to Pulau Jawa.Zone subduction is narrower at depth around 100 kms, so that the reservoir is narrower in

Bonjol area. It is possible that the reservoir is sedimentary rock which has experienced shear several times.

Componen combination of geothermal system is heat source, reservoar, and clay cap formed a certain geothermal system in this area. Geothermal systems spread along depresion struktur which forms a part of Sumatera fault systems.

Result of magnet survey shows approximation of potential prospect can be divided into two prospect areas. First prospect in north side related to manifestation Takis and Limau, while second prospect resided in southeast that is around manifestation Padang Baru.

The youngest volcanic is Binuang dome which is supposed to be a heat source for the geothermal system of the area. Gravity data reveal a high anomaly which is interpreted as an intrusive body beneath Takis hot spring.

Cap rock layer there is in depth around 500 m to 800 m, with resistivity value around 10 - 15 ohm-meters.

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

Sample Code	TAKIS HOTSPRING APT	SUNGAI LIMAU HOTSPRING APL	PADANG BARU HOTSPRING APPB	KAMBAHAN HOTSPRING APK	BATU AMPA COLDSPRING ADB
Elev.(m)	243	289	222	259	341
T(^{o}C) air	87,9	73,5	49,7	73,4	25,2
T(^{o}C) udara	28,6	30,6	29,0	27,4	25,2
pH	6,90	7,30	6,50	7,50	6,60
EC	5300	4040	5430	2020	17
(µS/cm)					
SiO_2(mg/L)	200,50	190,60	94,00	101,00	3,40
Al	0,00	0,00	0,19	0,00	0,00
Fe	0,12	0,08	3,91	0,06	0,01
Ca	79,70	32,40	161,80	20,1	0,00
Mg	1,45	4,17	39,60	0,09	0,10
Na	917	698	964,00	378	0,47
K	50,00	36,36	50,90	19,20	0,35
Li	2,70	1,75	4,10	1,05	0,00
As	0,20	0,40	0,30	0,20	0,00
NH_4	1,09	0,73	0,73	0,73	0,00
B	12,60	9,46	12,18	4,63	0,00
F	2,00	1,00	1,00	0,00	0,00
Cl	1512,12	1118,10	1336,86	580,48	0,00
SO_4	213,57	114,15	327,97	61,73	0,00
HCO_3	127,14	120,00	906,39	93,83	2,51
CO_3	0,00	0,00	0,00	0,00	0,00
meq cat	45,73	33,57	55,42	18,15	0,04
meq an.	49,29	35,93	59,44	19,20	0,04
% IB	-3,75	-3,41	-3,50	-2,81	-3,75

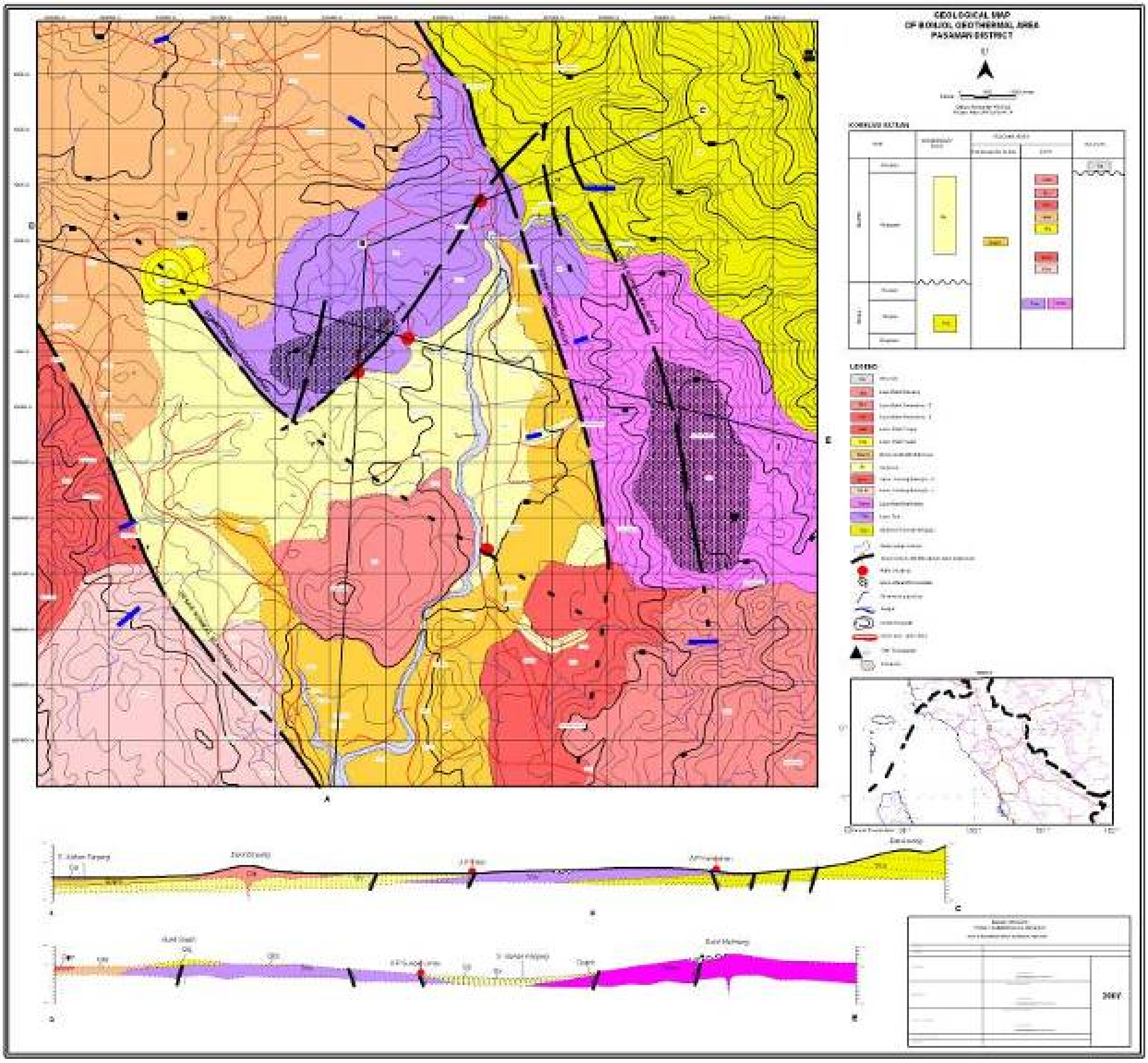

Figure 5: Geological map of Bonjol geothermal area.

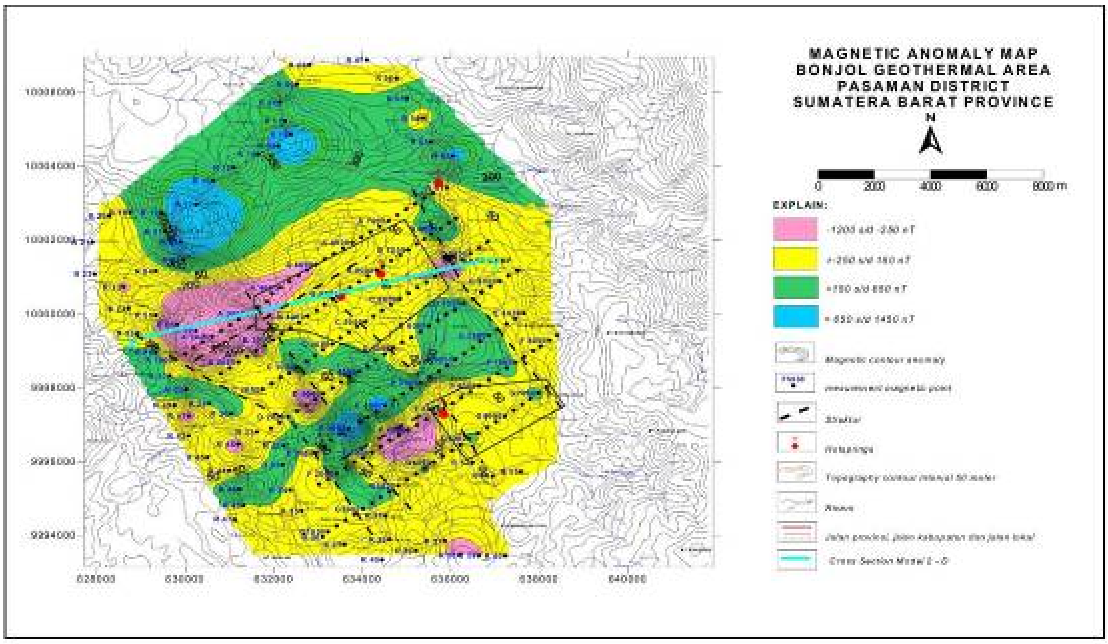

Figure 6: Magnetic map of Bonjol geothermal area.

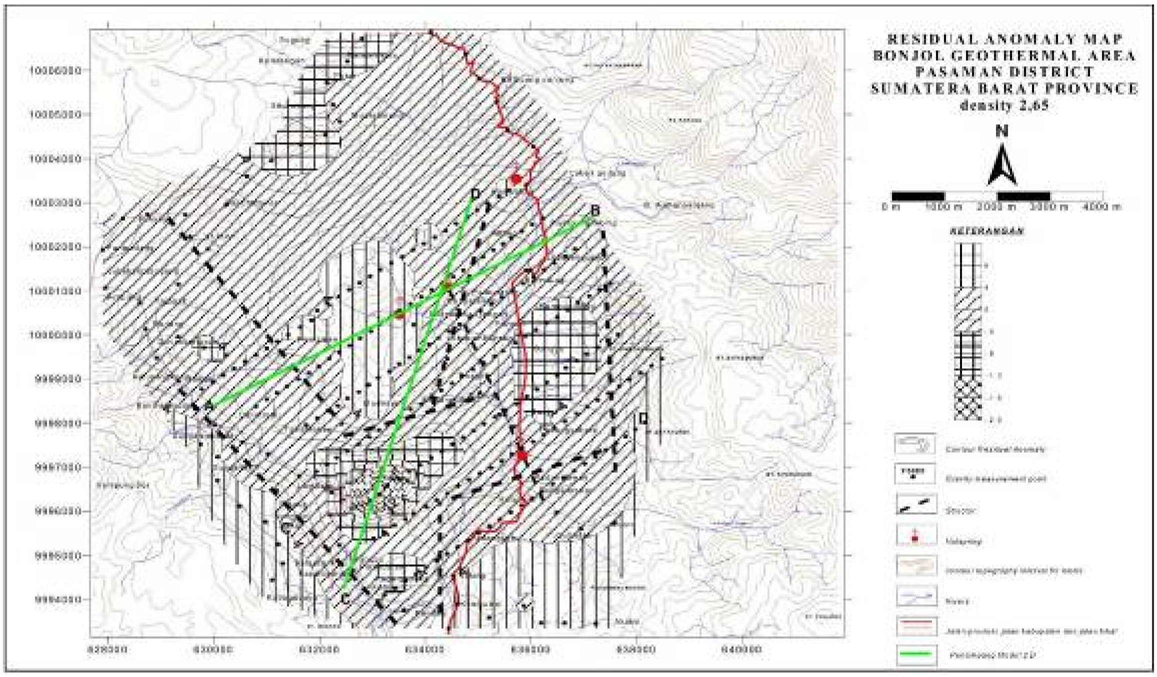

Figure 7: Residual anomaly map of Bonjol geothermal area.

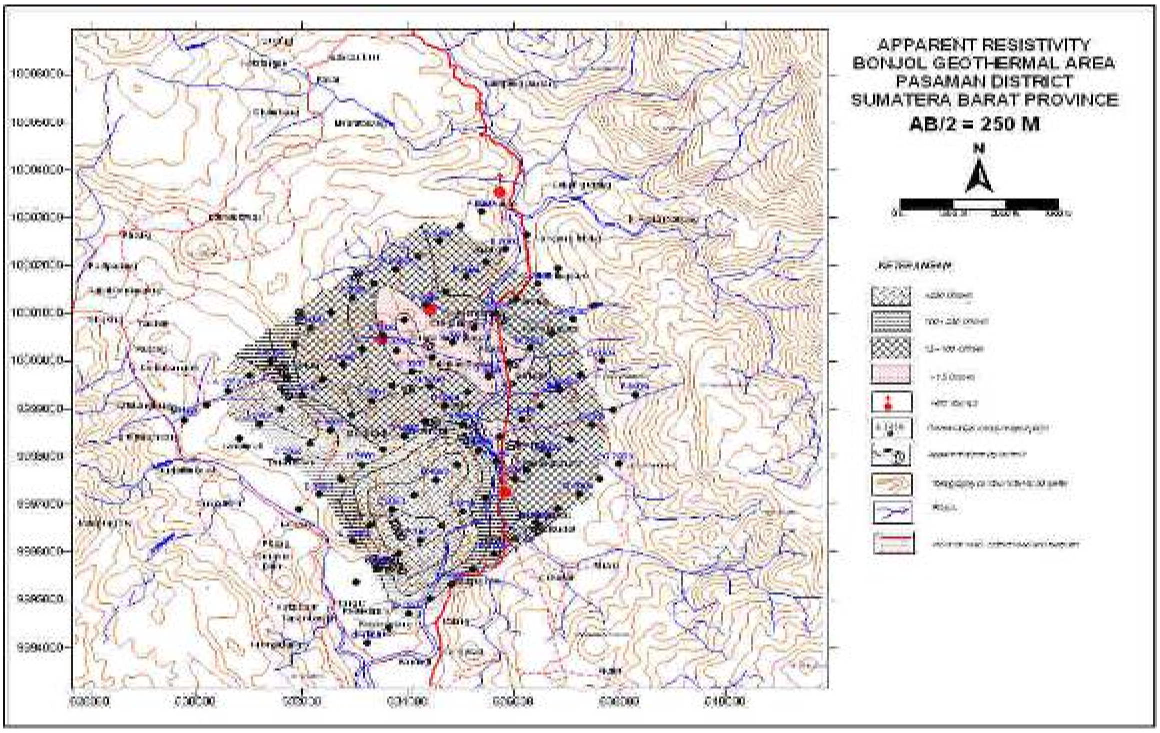

Figure 8: Iso apparent resistivity map with AB/2=250m of Bonjol geothermal area.

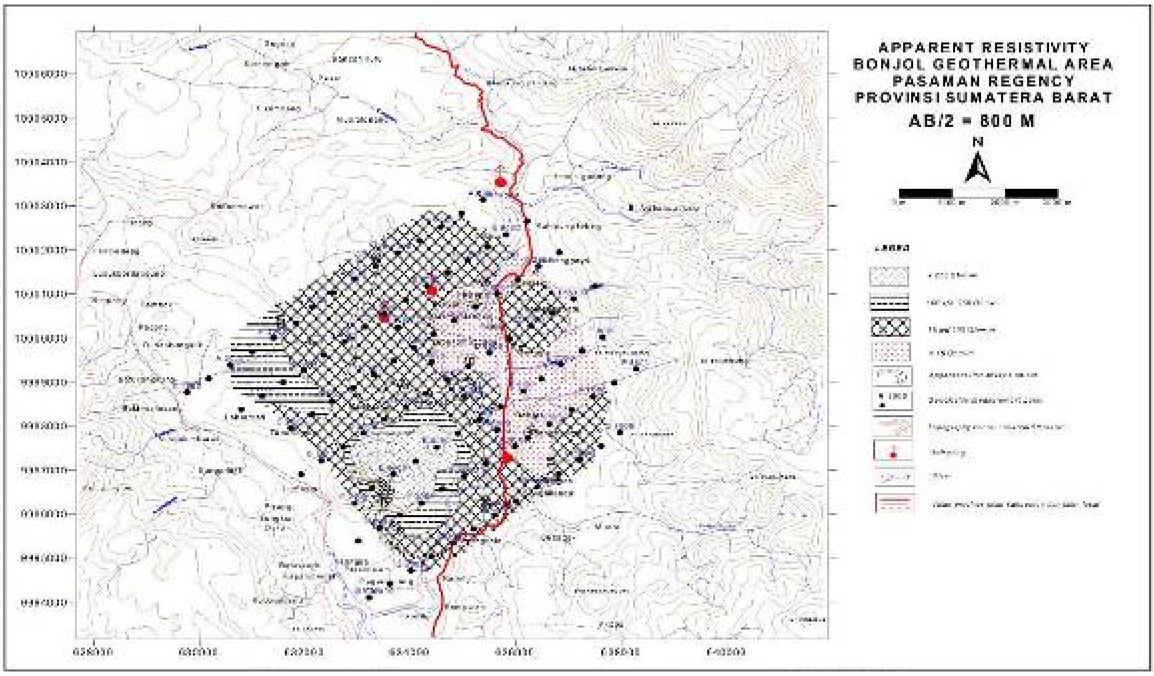

Figure 9: Iso apparent resistivity map with AB/2=800m of Bonjol geothermal area.

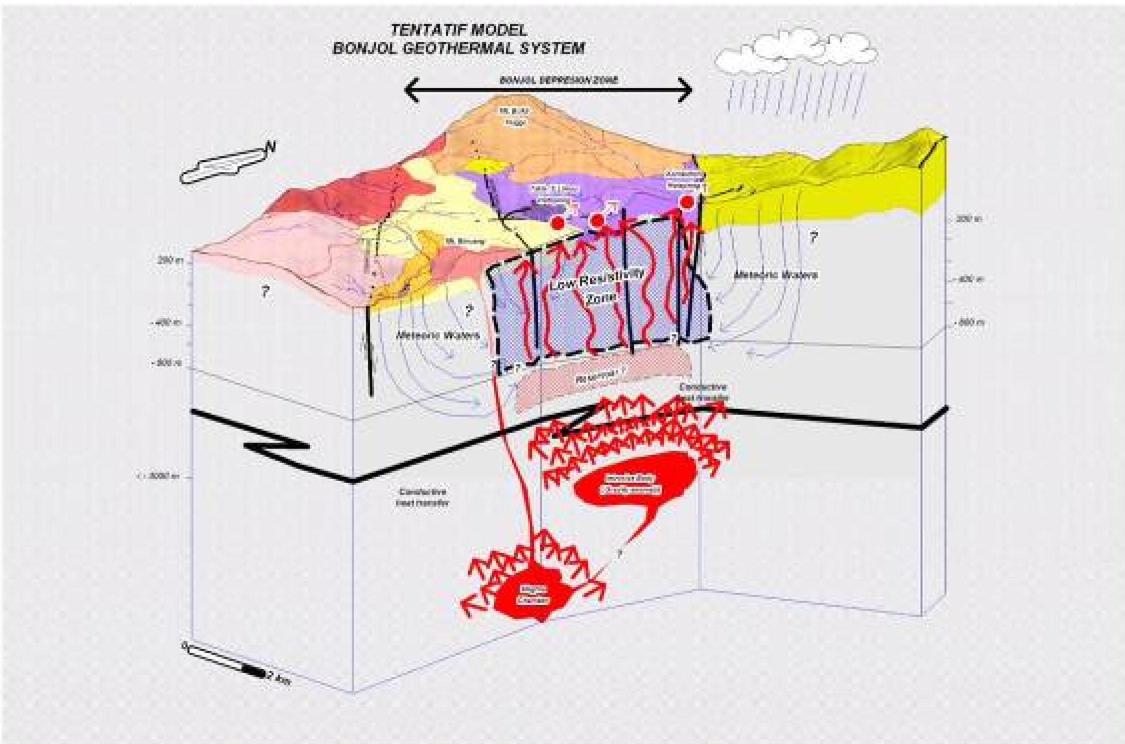

Figure 10: Tentative model of Bonjol geothermal area.