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Geothermal Conceptual Model of Talu-Tombang West Pasaman, West Sumatera Based on 3G Data Studies

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Abstract. Talu-Tombang geothermal system is one of the potential geothermal resources in West Sumatera. This geothermal system is indicated by the presence of warm water pool as surface manifestation at Talu (TA 1 and TA 2) and Tombang (TO 1 and TO 2). This study aimed to develop a conceptual model of the Talu-Tombang geothermal system. This study includes geology, fluid chemistry, gravity, and geoelectrical DC resistivity survey. Lithology present in the study area is Pre-Tertiary metamorphic rock, Tertiary sedimentary rock, Quaternary volcanic rock and alluvial. The existence of manifestations in this area is associated with NW-SE and NE-SW fault systems. The chemical analyses show that Talu waters have HCO3-Cl type and Tombang waters are SO4-HCO3 type. Result from the gravity survey shows the high residual anomalies of more than 30 mGal in the middle of the study area indicating an intrusion rock; the intrusion might act as a heat source. Reservoir fluid is meteoric water origin. Based on resistivity data, the low resistivity value below 100 Ohm-m is associated with alluvium product at the eastern area. Based on 3G data, the geothermal system has two reservoirs, i.e. Talu and Tombang reservoirs. Geothermometer of K/Mg show reservoirs have temperatures of 150±10°C.

Keywords: *conceptual model; geothermal; Pasaman; Talu-Tombang; West Sumatera.*

1 Introduction

A conceptual model is a schematic representation of the current best understanding of a geothermal system, consistent with all known data and information. An integrated conceptual model can be developed by combining all the information from geology, geochemistry, and geophysics data. A good conceptual model should encapsulate the geological framework, hydrothermal fluid pathways, reservoir temperature, isothermal line, and surface geothermal features, and should be consistent with all available data and information. The aim of this study is to develop a conceptual model of the Talu-Tombang geothermal system by integrating chemical and water isotope (18O and 2H) data of warm pool with a preliminary structural–geological map and geophysics data from [1]. Previous research from [2] has identified characteristics of the Talu- Tombang geothermal system from geology, geochemistry, and geophysics aspects. However, geochemistry model and hydrothermal fluid flow process are not explained yet. Previous research also has not covered reservoir origin clearly. Therefore, this study is required. The findings are significant to reduce exploration risk in study area.

Figure 1 shows the study area of the Talu-Tombang geothermal area that is in West Pasaman, West Sumatera Province. This location is around 200 km from the capital city of West Sumatera, Padang. Talu-Tombang geothermal area is part of Cubadak geothermal exploration and preliminary survey assignment area from government.

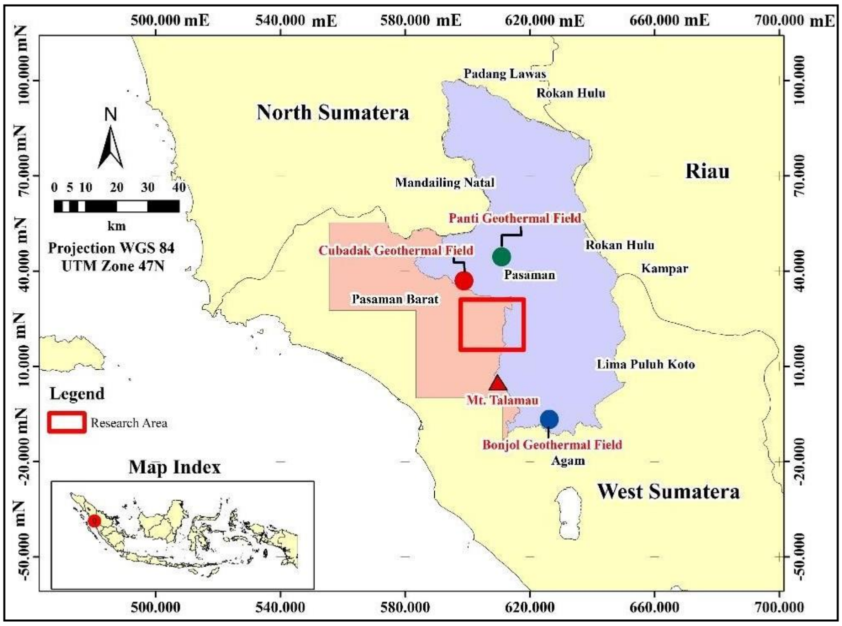

Figure 1 Administrative location of Talu-Tombang geothermal area

2 Data and Analysis

Data collection technique in this study uses secondary data obtain from [1]. Required data are water chemistry data, geological map, gravity, and resistivity data. Water chemistry data analysis has been conducted on 4 warm waters (TA

1, TA 2, TO 1, and TO 2) and 3 cold water from river (AI Angek, Bt Tinggam, Bt Sopan). The distribution/location of samples is illustrated in Figure 2. The result of this analysis is to interpret origin the fluids, hydrothermal fluid process, and estimate reservoir temperature. Additionally, gravity data was modelled in the study by using Oasis Montaj software.

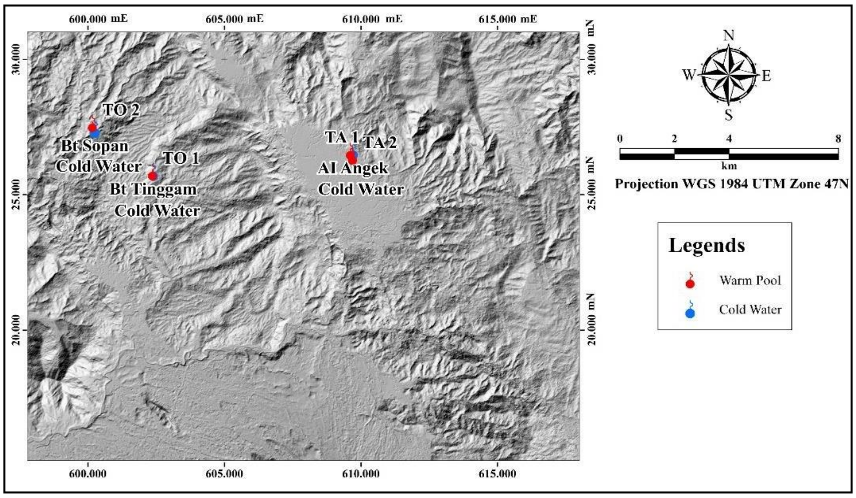

Figure 2 Surface manifestation location map of Talu-Tombang geothermal area with DEMNAS as the background. Data is retrieved from [3].

3 Result and Discussion

3.1 Geothermal System and Geological Setting

Determination of geothermal system in Talu-Tombang area refers to [4]. The study area is classified as non-volcanic geothermal system. This type of geothermal system is not directly related to Quaternary volcanism. In general, it consists of Pre quaternary rock formations. This is shown by the geological map of the study area which shows predominantly Tertiary volcanic products (Figure 3).

Based on Sumatra Island physiography from [5], the study area is included into Barisan Mountain which is have a Permo-Carbon until Mesozoic rock. The lithology stratigraphy and geological map of this area is modified from [1], especially in cross section. Rock type in the study area comprises 13 rock units from oldest to youngest (Figure 3). The formation of the lithostratigraphy unit in the study area took place from Pre tertiary to Quarternary. The oldest rocks are metamorphic (Ptq), metalimestone (PTmg), and ultramafic (PTu) were deposited in Pre-Tertiary age. Then in Oligocene age, sandstone formation (Tbp) was deposited. Volcanism products are deposited during Miocene- Pleistocene age in this area i.e. Sarik lava (Qls), Cubadak piroclastic 1-2 (Qapc 1 & 2), Sarik pyroclastic (Qaps), Tabal basalt lava (Qlt), and Godombong lava (Qlg). In Quarternary, Alluvium (Qa) is formed in Holocene age.

The existence of Talu-Tombang geothermal system is indicated by presence of surface manifestation in pull apart system, namely warm pool in Talu (TA 1 and TA 2) and Tombang (TO 1 and TO 2). Talu surface manifestation is associated with Talu fault which has northwest-southeast orientation. Then, Tombang surface manifestation is associated with Tombang and Semut fault which has northeast-southwest orientation. The difference of orientation between Talu and Tombang can cause faults that are not connected to each other. It is identified that Talu and Tombang come from different depression systems as well. Based on this condition, Talu and Tombang geothermal system can be divided into two different reservoirs. It will also be supported by geochemistry study which explained in the result and discussion, especially at geoindicator section (3.2.2).

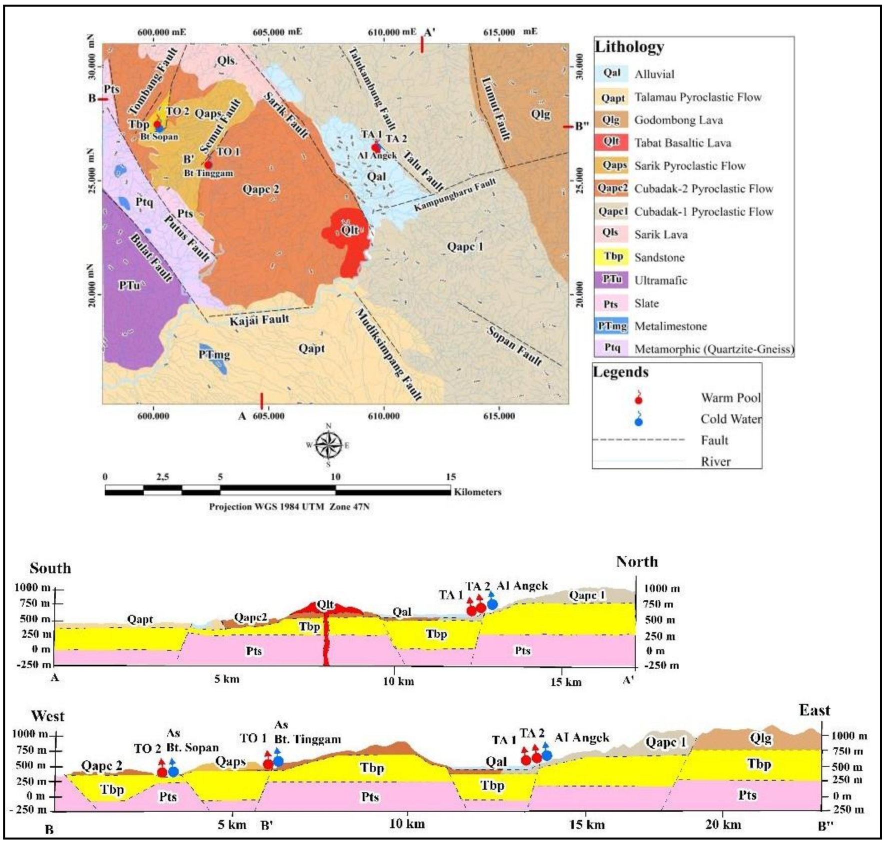

Figure 3 Geological map of Talu-Tombang geothermal area is modified from [1].

3.2 Geochemistry

All the thermal discharges are categorized as warm pools, having temperatures below 50°C. The pH value of warm pool waters under investigation ranged from approximately 7-7.8. The general description of each surface manifestation can be seen on Table 1.

Table 1 Summary of observation and physical measurement warm and cold water in Talu-Tombang geothermal area from [1].

No	Sample Name	T (°C)	pH	Z (masl)	Flow (L/s)
1	TO 1	49.4	6.9	481	0.1
2	TO 2	48.3	7.7	336	1.5
3	TA 1	40.7	6.9	511	2
4	TA 2	40.4	7.8	508	0.1
5	AI Angek	25.6	6.2	510	5
6	Tinggam	23.3	6.7	474	70
7	Bt Sopan	25.4	6.5	337	40

The result of chemical analysis of major elements in Talu-Tombang samples dominantly have ionic balance of less than 5%, except TA 2. Therefore, water analysis using TA 2 samples must be careful. There are variations in the composition of chemical elements from each Talu-Tombang warm water pools group. Based on chemical composition, Talu samples have high HCO3 (120 to 210 mg/L) and Mg (6 to 7.7 mg/L). It seems that Talu samples indicate a mixing between hydrothermal fluid and meteoric water. Using a ternary diagram, the results of the water chemistry analysis may reveal type of geothermal water, reservoir temperature, and geoindicator. Geoindicator can also be used to determine how many reservoirs are in the study area.

3.2.1 Type of Geothermal Water

Thermal water discharged in Talu-Tombang is immature HCO3-Cl and SO4-HCO3 water (Figure 4a and 4b). Based on diagram Cl-HCO3-SO4, warm pool in the studied area can be divided into two water types (Figure 4a). Bicarbonate-chloride water comes out of warm pool in Talu. These warm pools experience a dilution process with HCO3 water during lateral flow. This type of water is formed by the mixing of the water in the reservoir that contains high Cl with groundwater which is has high bicarbonate content (dilute waters). Thus, it is interpreted that Talu warm pool are produced by the process of mixing hydrothermal fluids with meteoric water. This interpretation has been supported by Na-K-Mg ternary diagram plot which shows immature water (Figure 4b). Sulphate-bicarbonate water is coming out of Tombang warm pool shows that it was formed in the shallowest part caused by water rock interaction in the sedimentary rock horizon. In this case, Tombang 2 (TO 2) lies at sandstone (Tbp) as shown in Figure 3.

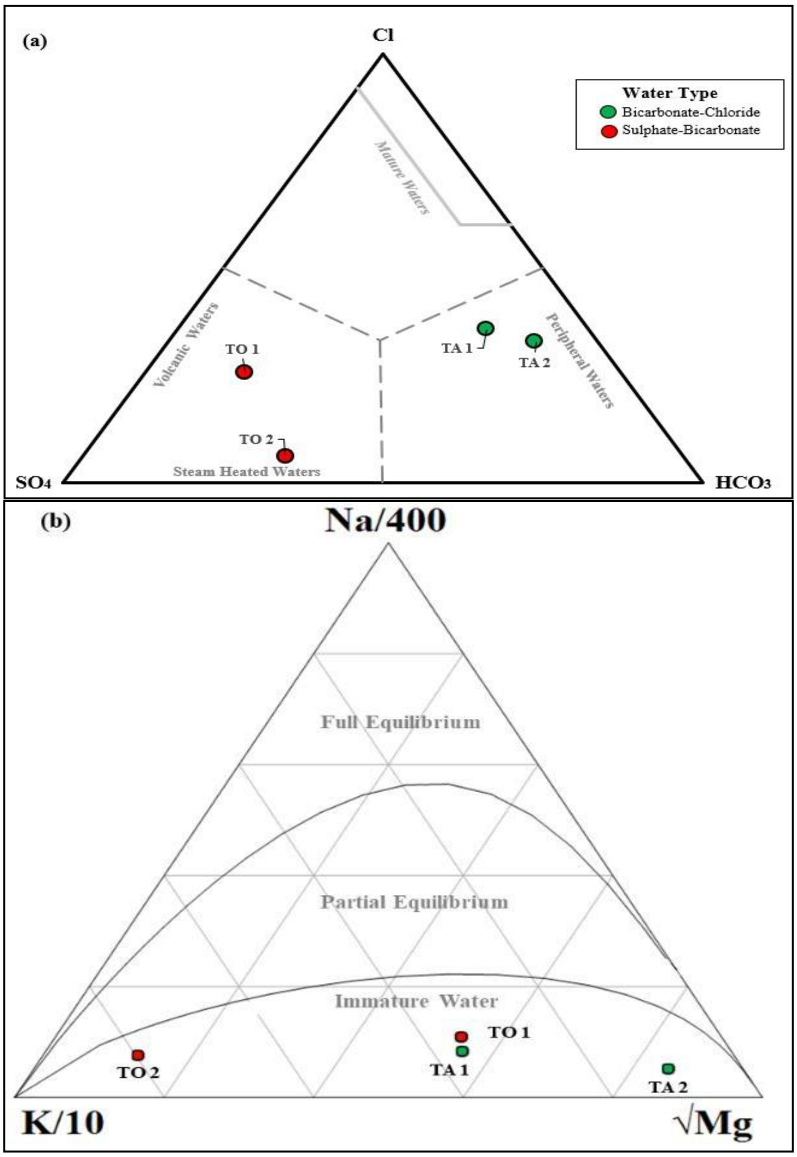

Figure 4 Ternary diagrams of (a) Anions Cl-HCO_3-SO4 and (b) Cations Na-K-Mg.

3.2.2 Geoindicator

Common reservoir can also be determine based on Cl-Li-B ternary diagram and Cl/B ratio. According to Cl-Li-B ternary diagram, it can be interpreted that all samples of Talu-Tombang warm water pools have low B/Cl ratio, less than 50% (Figure 5). This is supported by the relatively higher concentrations of Cl (150 mg/L) compared to Li (0.16 mg/L) and B (2.09 mg/L) in the samples. The diagram also shows the Cl and B contents of the Talu-Tombang warm water pool samples tending away from the Li direction. Li is possibly taken up into clays in near-surface reactions [6]. Surface manifestation that lies in Talu area (TA 1 and TA 2) show adjacent to one zone, even in Tombang area (TO 1 and TO 2) too. It is estimated that warm pool coming out in the study area from two different reservoir.

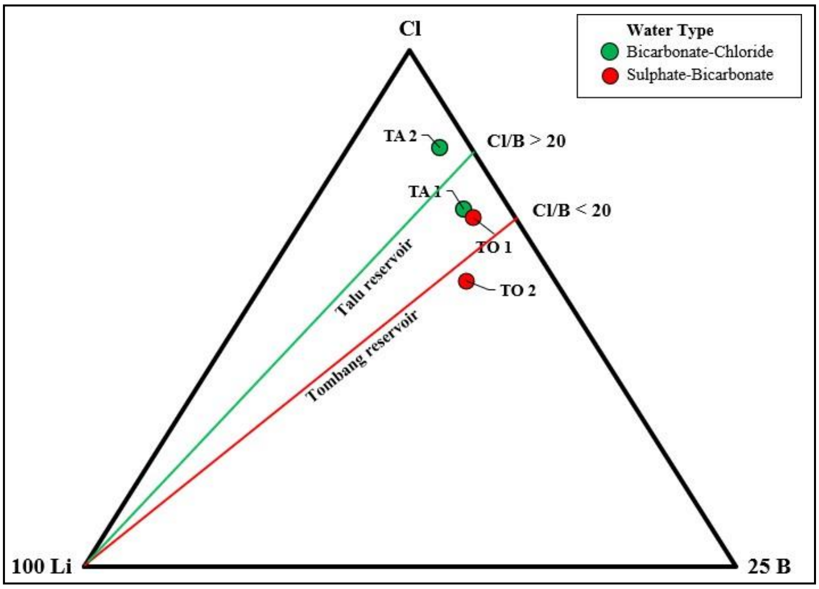

Figure 5 Ternary diagram Cl-Li-B diagram shows two trendline Cl/B cluster, the first one consists of TA 1 and TA, the second one is consist of TO 1 and TO 2. The trendline showed there are two different reservoirs in Talu-Tombang geothermal area.

Ratio of Cl/B showed that Talu warm water pool sample group had a higher ratio than the Tombang group (Figure 5). This shows that the Talu warm water pool sample group has experienced more intensive mixing with groundwater. This is also supported by the type of water in the Talu group in the form of bicarbonate-chloride. The low Cl/B ratio is caused by water rock interaction process which makes water obtain Boron element from secondary minerals of the rock during the weathering process.

Ratio of Cl/B can also be used to determine common reservoir in study area. According to Figure 5, it is likely that these 2 separates group manifestation originated from two different reservoir, one that lies to Tombang and one that lies to Talu. The determination of the two reservoir groups support geological condition in study area which shows the presence of Talu and Tombang manifestations associated with the two depression system.

3.2.3 Origin of Geothermal Fluid

Based on the stable isotopes δ18O and δ2H trend in Figure 6, all samples are plotted along the local meteoric water line. This show meteoric water is the main source of geothermal fluid in Talu-Tombang geothermal field. Analysis of the chemical characteristics and the type of water sampled from the Talu- Tombang warm water pool also supports that the hydrothermal fluid is affected by meteoric water which has a high HCO3 content (200 mg/L).

Table 2 Comparison of all calculated geothermometer from Talu-Tombang thermal waters

Samples	Conductive Quartz	Adiabatic Quartz	Chalcedony Conductive	K/Mg (Giggenbach)
			˚C	
TO 1	113	112	84	84
TO 2	108	108	79	152
TA 1	147	141	122	84
TA 2	146	140	120	46

The K-Mg geothermometer was used to estimate reservoir in study area. This geothermometer is give best result for sample that have experienced mixing process. K/Mg elements experience a faster reaction and can be used to estimate lower reservoir temperature. In this study, Tombang 2 (TO 2) sample is favorable to represent reservoir temperature in study area. Tombang 2 (TO 2) has relatively high direct discharge (1.5 L/s) compared to other samples. Magnesium (Mg) element content of TO 2 is only 0.15 mg/kg which indicate this sample mix with meteoric relatively low. Besides that, refers to Na-K-Mg diagram (Figure 4b), sample plot of TO 2 is closer to partial equilibrium than other samples. Therefore, reservoir has a temperature of 150±10°C that is classified as medium enthalpy geothermal resource [8].

3.3 Geophysics

3.3.1 Gravity

Gravity data are available to identify a range of geological structures related to intrusion and fault [9]. The residual anomaly in the study area has a value -35 to 55 mGal, with high density anomalies (>30 mGal) in the center part of Talu (TA 1 and 2) and Tombang (TO 1) manifestation. According to [10], high density anomalies is associated with intrusion body. The low anomaly area (below -5 Ohm-m) in Talu manifestation (TA 1 and 2) is estimated to be an alluvial product that correlates with geological map. The fault pattern has NW- SE and NE-SW orientation, separating high and low anomaly as illustrated dashed line in Figure 7a.

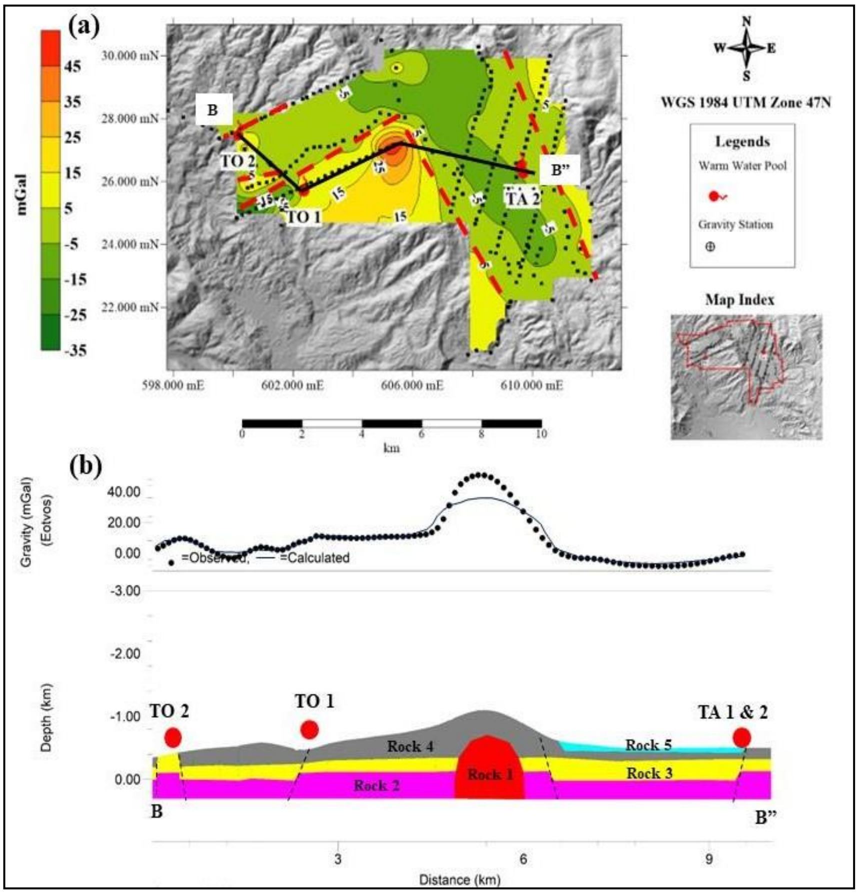

Figure 6 Gravity data processing of Talu-Tombang geothermal area with data source from [1]: (a) residual anomaly map (b) gravity 2D model profile from residual anomaly.

The cross-section model of subsurface density distribution of NW-NE direction correlated with manifestation (Figure 7b). The depth is adjusted according to geological model. The density distribution model obtained a density value between 1.7 g/cm3 to 2.7 g/cm3. In this path, study area consists of five body rock layers. The first rock body (2.7 g/cm3) in the middle of study area can be interpreted as an intrusion body and might as a heat source. High density below the surface is associated with high gravity anomaly. The second rock body is ranged from -250 to 250 m depth with a value 2.8 g/ cm3 associated with metamorphic rock. The third rock body with a density value of 2.3 g/cm3 interpreted as sandstone (depth 250 to 750 m), density 2.4 g/cm3 interpreted as 4th body, pyroclastic rock (depth 750 to 1000 m), and low density (1.7 g/cm3) is interpreted as 5th rock body, alluvium (depth 500 m). All density value and associated rock are refers to [11]. The presence of Talu-Tombang manifestation comes out through the fault.

3.3.2 Resistivity

For each resistivity station, four measurements are taken to reflect the changes in the distance between the current electrodes. These measurements provide an average representation of the geoelectrical conditions at different depth. According to [10], depth penetration target 100 meters is needed electrode (AB) spacing of 500 meters. The result of DC resistivity survey is illustrated in Figure 8.

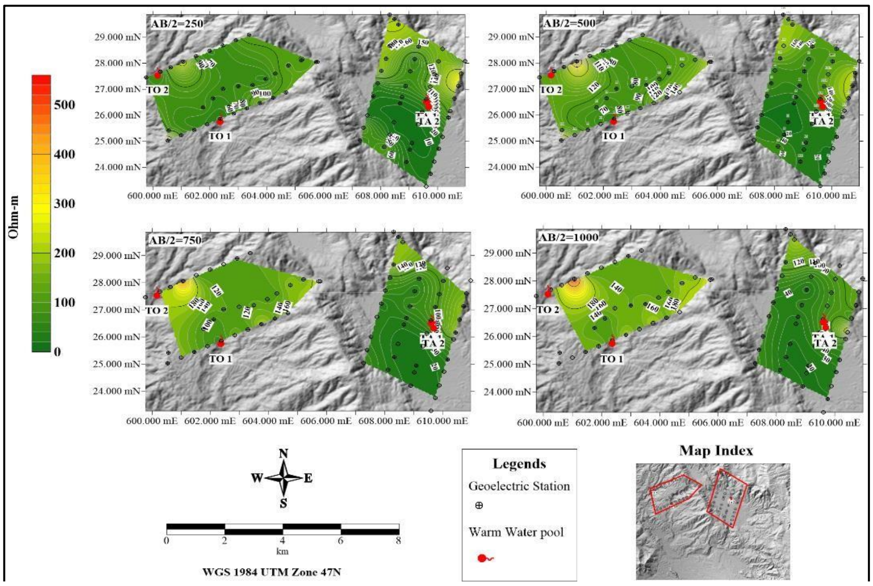

Figure 7 Resistivity map of Talu-Tombang geothermal area with data source from [1]. Low resistivity (<10 Ohm-m) is marked by black dashed.

From the resistivity contour map, the result of geoelectric data processing in the area around manifestation shows a low resistivity zone (<10 Ohm-m) at AB/2=250 or ~80 m depth which is interpreted as alluvium product. The sedimentary product in study area is seen at depths of 160 to 300 meters or AB/2=500 to 1000. The high resistivity area (>200 Ohm-m) at AB/2=1000 or 300 m depth, especially in the east of TO 2 can be interpreted as metamorphic rock.

4 Conceptual Model

The conceptual model of Talu-Tombang geothermal system is shown in Figure 9. The study area was determined to consist of two reservoir groups, Talu and Tombang reservoir with 3G data support.

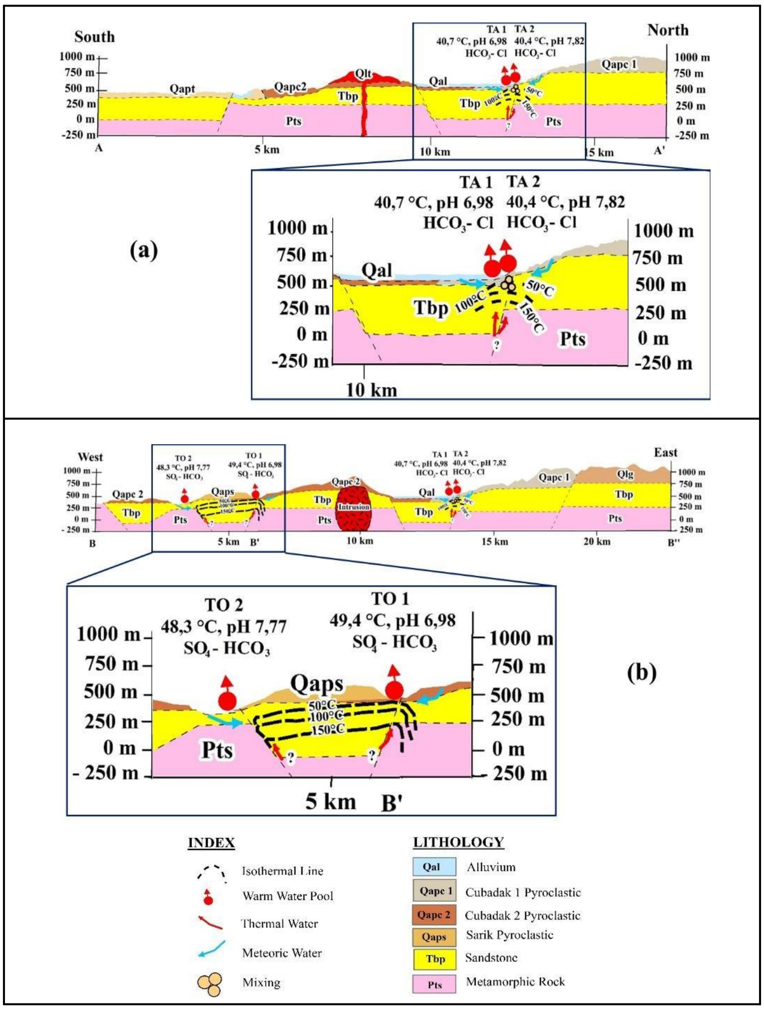

Figure 8 Conceptual model of study area: (a) for Talu (b) for Tombang geothermal area. Geological cross section is taken from Figure 3.

In order to create a geothermal conceptual model of Talu-Tombang geothermal system, the geological model in Figure 3 is modified using the result of gravity modeling (Figure 7) and is given in Figure 9b. The geological setting shows that between Talu and Tombang is in a different depression system. Geochemical data is indicated by the Cl/B ratio, there are two groups of different ratio values between the Talu and Tombang reservoirs as shown in Figure 5. The reservoir fluid is estimated to have a temperature of around 150±10°C based on K-Mg geothermometer calculations. Using boiling point depth curve, reservoir has depth ±220 m. The reservoir fluid is meteoric water origin. Near the surface, the reservoir fluid mixes with groundwater before discharging as hot spring in study area. For Talu reservoir, water type of warm pool is mixed bicarbonate-chloride water (Figure 4a). The emergence of this type of mixed warm pool tends to be controlled by active faults [4]. In this case, this area is controlled by Sarik and Talu Fault (Figure 3). For Tombang reservoir, water type of warm pool is sulphate-bicarbonate water. The emergence of surface manifestation of Tombang (TO 1 and 2) is related to Tombang fault and Semut fault (Figure 3).

Geophysical data indicate that the study area has a high gravity anomaly associated with intrusion body. The intrusion is covered by pyroclastic layer according to geophysical modeling. Then, the distribution of low resistivity value (<100 Ohm-m) is thought to be an alluvium or sedimentary rock product with 80 to 200 m depth. The existence of the intrusion in the study area also can separate reservoir sectors between Talu and Tombang.

5 Conclusion

Talu-Tombang is geothermal system is indicated by the presence of warm pool surface manifestation which has northwest-southeast orientation fault controlled. Talu warm pool group belongs to the bicarbonate-chloride water type, while Tombang warm pool group is sulphate-bicarbonate water type. Both warm pools are immature water. The reservoir in the study area is divided into two reservoir groups, Talu and Tombang. The reservoir is located at ±220 m depths with temperature 150±10°C or medium enthalpy. Infiltration comes from meteoric water according to isotope diagram. Gravity data show high anomaly value more than 30 mGal is considered an intrusion body, while low anomaly below -5 mGal is alluvium. The fault pattern of Sumatra is also detected in gravity data with separating between high and low anomaly zone.

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