Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal System of Sorik Marapi - Roburan - Sampuraga, North Sumatera, Indonesia

Yuanno Rezky and Dudi Hermawan

Center for Geological Resources, Geological Agency. Jl. Soekarno-Hatta No. 444 Bandung 40254, Indonesia

yuanno@gmail.com, hermawan_dudi@yahoo.com

Keywords: Sorik Marapi - Roburan - Sampuraga, Geothermal system

ABSTRACT

This paper comprises the study of prospect condition representation, reservoir characteristic and constraint possibility. Study approach is carried out by applying qualitative method and quantitative analysis.

The study result shows there are 3 geothermal prospect areas in Sorik Marapi - Roburan – Sampuraga Working Area (WKP), they are: Sibangor prospect, Roburan prospect and Sampuraga prospect.

Sibangor prospect is related to volcanic system and considered at risk to develop, considering the volcanic hazard potency of Gunung Sorik Marapi. Meanwhile Roburan prospect area of about 15 km^2 (upflow) and Sampuraga 14 km^2 (outflow) are related to the geothermal system, therefore these two areas are good potential areas to develop.

Reservoir of geothermal system in Sorik Marapi area is interpreted formed in undifferentiated volcanic which bordered by footwall of Gadis fault which has NW - SE strike direction. Reservoir of Roburan prospect area is estimated to have two phase system with temperature of 270 - 290°C thickness of 1000 m where its top at 900 to 1000 m and shallow reservoir at depth of 600 m. Reservoir of Sampuraga prospect area is estimated to have water dominated system with temperature of 220 - 230°C thickness of 800 m where its top at 1200 m. Heat sources is interpreted as cooling magma which probably associated to the young volcano of Sorik Marapi.

1. INTRODUCTION

The Indonesian archipelago is mostly located in the path of a volcanic belt with the potential for the formation of geothermal energy. One of volcanic geothermal potential is Mount Merapi Sorik.

Sorik Marapi geothermal area are recognized by the existence of surface manifestations such as fumarol and hot spring. This area is located at a depression zone which is developed by fault structures, which are part of Great Sumatera Fault.

The objective of this paper is to discuss the ccharacteristics of Sorik Marapi geothermal systems as a reference design or appropriate exploration strategy plan.

Geothermal area of Sorikmarapi - Roburan - Sampuraga is part of the Mandailing Natal regency in North Sumatra Province administrative area (Figure 1.1). Geographically, Sorikmarapi - Roburan - Sampuraga Working Area is located at the coordinates boundary of 99 ° 28'55 .54 "- 99 ° 48'1 .22" E and 0 ° 31'17 .45 "- 0 ° 53'17 .78" N (Figure 1).

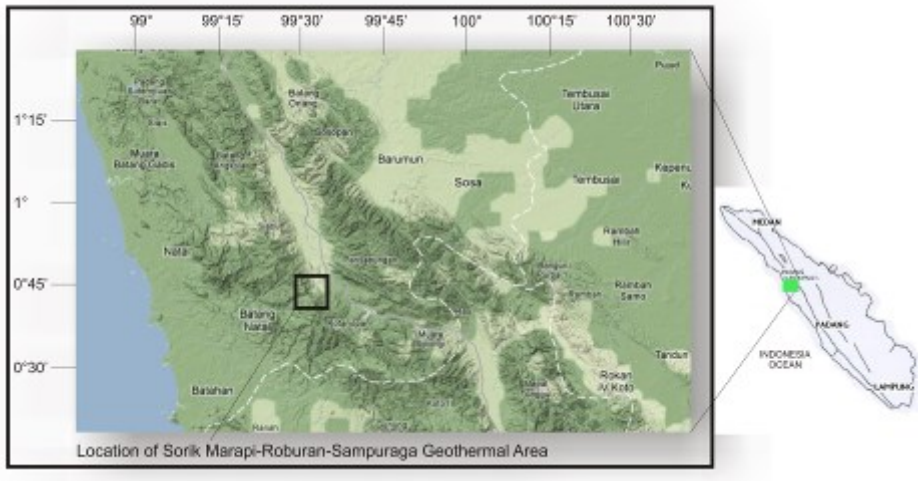

Figure 1: Location map of Sorik Marapi-Roburan-Sampuraga geothermal area

2. GEOLOGY

Physiographic of geothermal area Sorik Marapi - Roburan - Sampuraga according to N.M.S Rock, et al, (1983) is a part of the Western Bukit Barisan Volcano Range Zone. This Zone forms a stretched volcano range, separated by graben. The western graben

has been arranged by meta volcanic and meta sedimentary in Late Mesozoic age, granitoid intrusion, and then covered by resistant and volcanic sediments in Miocene age that is then further precipitated volcanic rock in Quarter age. The Volcano Sorik Merapi is an active volcanic type-A crater-lake stratum with peak height of 2145 m (Suganda, vsi.esdm.go.id). While the prospect area of Sampuraga is included into Graben Zone where this graben tends to the northwestern – southeastern as seen at Panyabungan area (Panyabungan Graben), Rao (Rao Graben) and Lubuk Sikaping (Sumpur Graben), known as Sumatera Fault System.

Generally the rock at the geothermal area of Sorik Marapi – Roburan – Sampuraga can be classified as surface deposition, quarter and tertiary volcanic depositions and metamorphic rock. Metamorphic rock is interpreted as basement rock, and then uncomfortably is covered by young volcanic rock as a result of volcanism pre- and activity of Volcanic Sorik Marapi, and sedimentary deposition and alluvial.

Geologic structure developing at this area is northwest-southeast oriented normal fault (forming graben Panyabungan) as oriented as the general pattern of The Great Sumatran Fault structure at the eastern study area restricting the old volcano range series (meta-limestone unit), with group of young rock (tuff unit of Sorik Marapi, breccia volcanic andesite pyroxene rock unit of Sorik Marapi II).

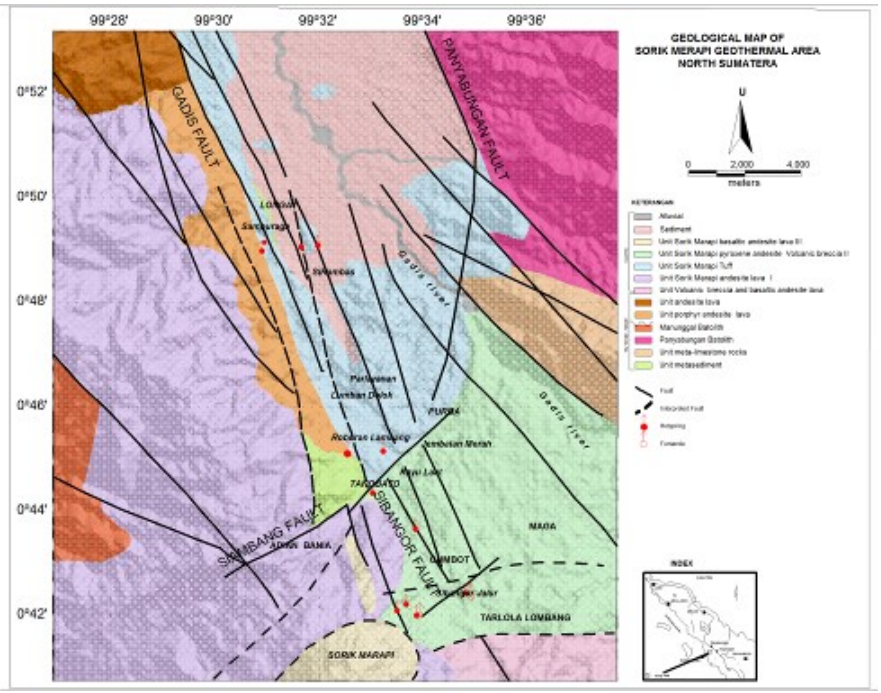

Figure 2: Geological Map of Cubadak Geothermal Area, West Sumatera

Geothermal manifestation being at Sorik Marapi-Roburan-Sampuraga area spreads sufficiently widely in the environment of Sumatera fault structure system. Manifestation in the forms of fumarole and hot spring is divided into three groups; those are the end southern Sibangor group, Roburan group at central part, and Sampuraga group at the end northern.

The type of geothermal manifestation is in the form of fumarole at temperature of 90 – 94,5°C and hot spring at temperature of 36 – 99°C.

3. GEOCHEMISTRY OF GEOTHERMAL MANIFESTATION

Geochemical analyses show that the hotspring of Sampuraga is in the type of chloride - bicarbonate indicating the characteristic of outflow zone of the geothermal system of Sorik Marapi. With the high ratios of Na/Ca and Cl/SO4, it indicates outflow of reservoir at the boiling condition (+/- 300 °C) which in the course to the surface it undergoes a mixing with shallow ground water (A. Nasution, S. Primulyana, ITB, 2007).

The boron concentration of crater water and hot water of Sampuraga is sufficiently high (18.33-24.61ppm) it has been expected that the level of the rock solubility occurs at high temperature, particularly sedimentary deposition and reservoir is approximated to dominate by hot water (water dominated system) supported by the high discharge of hot spring as the geothermal manifestation.

Whereas with the emergence of fumaroles and the chloride - sulfate typed at the group of Roburan manifestation indicates that the area as up flow zone of the geothermal system of Sorik Marapi.

Meanwhile the bicarbonate –typed hot water of Roburan Dolok -2 with pH neutral, indicates that gas CO2 rising up to the surface contacts to the shallow ground water (A. Nasution, S. Primulyana, 2007).

In addition to the location that does not too far from the eruption center of Volcano Sorik Marapi, the high content of SO4 and Cl as well as the acid pH in the group of Sibangor manifestation supports the rationale that the manifestation in this area is more associated with volcanic system of the geothermal system itself.

4. GEOPHYSICS

4.1 DC Resistivity

Horizontal dissemination of resistivity (Figure 3) provides an high anomaly trend (> 25 ohm-m) being at the western in the high topography, whereas at the lower elevation at the eastern and the central is filled by low resistivity (<10 ohm-m). In general there are 3 resitivity areas.

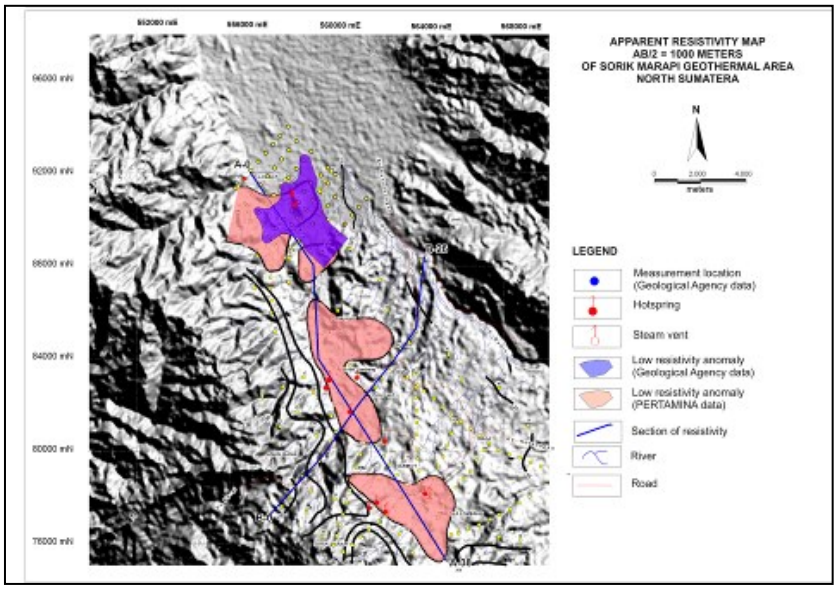

Figure 3: Map of Apparent-Resistivity AB/2 = 1000 m of Sorik Marapi area.

The low resistivity at the northern with the area of ± 8 km^2 coincided to the location hot water manifestation of Sampuraga, at the central with the area of ± 12 km2 around the manifestation of Roburan and at the southern of ± 9 km2 where there is manifestation of Sibangor. The three low anomaly groups are located at one alignment reflecting a main fault in the area (Gadis Fault).

The low resistivity anomaly is caused by the layer of saturated rock with hot fluid or the layer of altered rock as a result of geothermal activities. The hot fluid comes from condensed water at the depth rising up to the surface through the rock splits. The rock surface in this area at the southern and western parts is covered by lava, while at the northern is restricted by lava tongue passing through a narrow lane cut-crossing the fault surface.

This condition separates (resistivity discontinuity) low anomaly at central part (Roburan) and northern (Sampuraga). The separated two anomalies is possibly caused by the limited data of measurement or controlled by geological structure.

4.2 Gravity

Gravity anomaly (Figure 4) highly reflects regional geological structure of Sumatera that is in northwest-southeast direction. The emergence of three geothermal manifestation groups (Sampuraga, Roburan and Sibangor) is located at depression zone. This zone is a depression/graben area wedged-in by two big structures at northwest-southeast direction that is Gadis Fault for the left-hand structure, and right-hand Panyabungan Fault. This depression zone as split zone so that the hot fluid can appears on the surface.

The high Anomaly which at the western and eastern is caused by high-density rock in the form of volcanic rock of Volcano Sorik Marapi at the southwestern and basement rock disclosed widely at the eastern in this area. The low anomalies at Sampuraga, Roburan and Sibangor Tonga reflect the quarter-aged rock that has undergone a change as a result of geothermal activity.

The highest rock density is volcanic rock of Sorik Marapi, pre-tertiary basement rock and the lowest pyroclastic deposition.

The subsurface structure at the northern part is associated with penetration rock at Sampuraga and tertiary rock. The penetration rock has low density about 2.1 gr/cm^3 because it has undergone a change, while the tertiary rock at the depth of 300-400 meter and at the central part the depth is up to 600 meter; this is associated with depression zone.

There are several (shallow) quarter-aged structures at the central that directed nearly west east, at the vicinity of the peak of Sorik Marapi that directed nearly southwest – southeast and at the southern that directed nearly west-east.

The central-hand structure indicates that there is an alignment cutting the older structure (Gadis Fault and Panyabungan Fault) that directed nearly west east. The structure that directed southwest – northeast cuts Gadis Fault passing through Roburan manifestation.

It is possible that this structure controls the emergence of Roburan manifestation, from surface geology, this fault is named Siambang fault.

The structure at the southern that directed nearly west east to the direction of the location of Sibangor Tonga manifestation, this structure becomes to control the emergence of manifestation. This structure has been known as Sibangor fault (west-east).

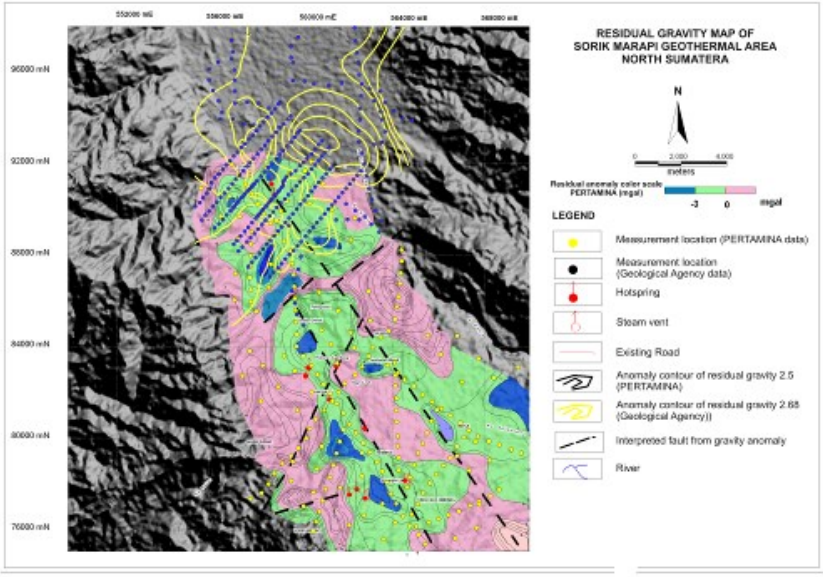

Figure 4: Gravity residual map of Sorik Marapi area

4.3 Geomagnetic

Magnetic anomaly (Figure 5) at the northern is lower than that at the southern; the low anomaly at the northern spreads from west to east. Anomaly zone is restricted by a fine contour pattern and steep gradient characterizes basin based by the shallow basement marked by tertiary basement rock at the northern and volcanic rock of Volcano Sorik Marapi at the southern.

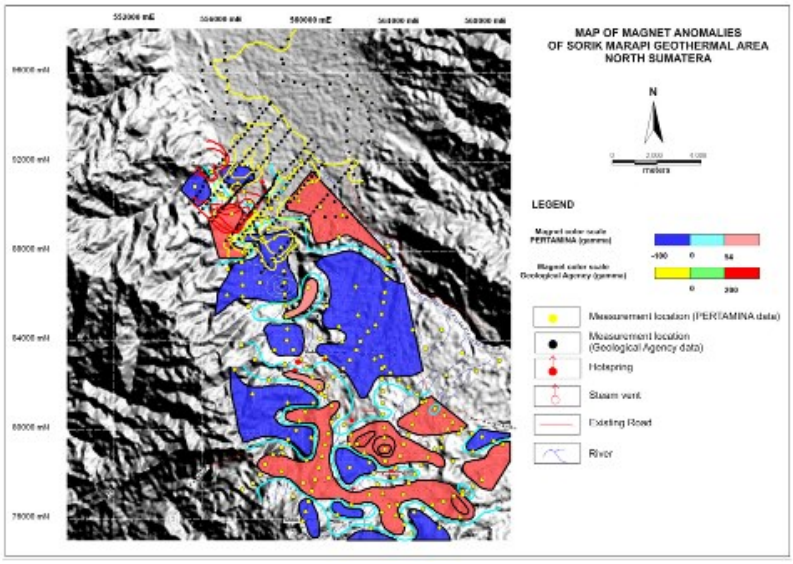

Figure 5: Magnetic residual map of Sorik Marapi area

The low anomaly at the middle of the eastern and western parts is caused by the existence of tertiary rock, while the northern to southern is occupied by anomaly with medium value interspaced to be low around the geothermal manifestation.

Medium anomaly reflects depression zone, whose the surface is filled by lava and pyroclastic deposition rock, while the low anomaly around manifestation indicates the strong hydrothermal effect as a result of geothermal system in this area, primarily at the southern.

The granite penetration rock around Sampuraga does not provide significant anomaly response, even to be lower than the anomaly as a result of sedimentary rock. This indicates the strong change occurring as a result of geothermal system of Sorik Marapi at the rock environment.

4.4 Magneto Telluric (MT)

The pattern of apparent-resistivity anomaly reflects the existence of depression zone border that directed at northwest – southeast. The southern manifestation group (Roburan dan Sibangor) indicates a relative low anomaly with the pattern at the northern tongue

and exposure to the southern, while the apparent-resistivity doesn't indicate an anomaly associated with the northern manifestation group (Figure 6).

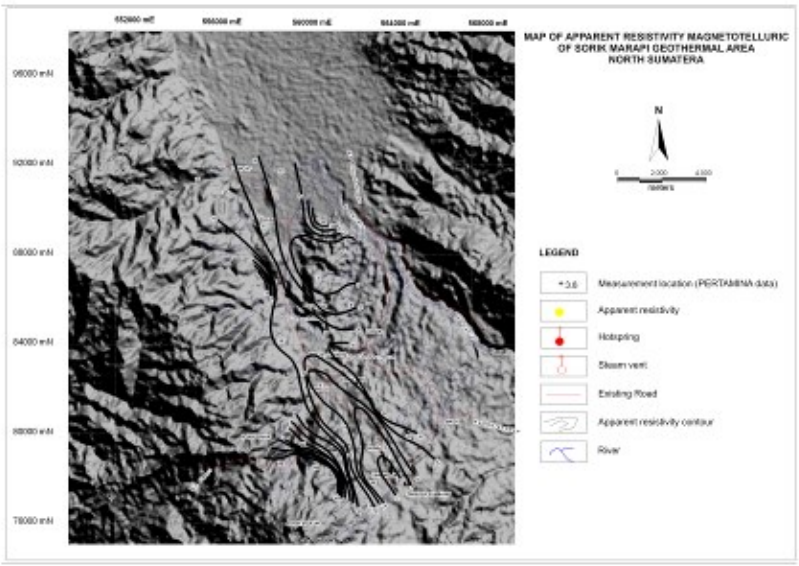

Figure 6: The apparent resistivity map (T=3 s)

The similar pattern is also indicated at the total conductance map confirming the prospect Roburan zone with the contour similar with dissemination apparent-resistivity (Figure 7).

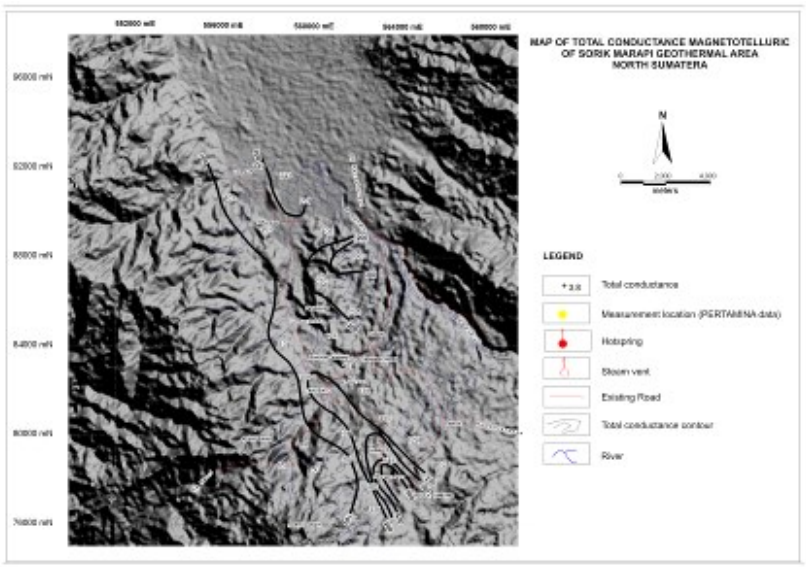

Figure 7 : Total Conductance (MT) Map

The subsurface layer indicates the existence of conductive layer as a cap layer and top reservoir as upper border of reservoir layer of geothermal system of Sorik Marapi area. Figure 8 shows the longitudinal section drawn from the south direction around Sibangor Julu manifestation passing through Roburan manifestation to Sampuraga manifestation.

The cap layer reflects the existence of the prospect area in this area such as divided into two; this has been seen that there is a discontinuity of this layer in the central area. The south part is a prospect Roburan zone and the northern is characterized by the emergence of Sampuraga manifestation.

The depth of southern top reservoir tends to be increasingly deeper to the northern. Top reservoir around Sibangor and Purba Julu is at the depth of 900 – 1000 meter, while at Roburan, the cap layer (< 10 ohm-m) there is a thin part and then filled-in by medium-resistivity layer (25 - 68 ohm-m) that is adequately thick before the contact with the high- resistivity anomaly.

The medium-resistivity layer is possibly a shallow reservoir with the reservoir peak is 600 meter under surface.

The depth of northern top reservoir (Sampuraga) is about 1200 meter under the surface with the thick of cap layer is approximately 300 meter. The pattern of this cap layer underwent a southern discontinuity, exactly similar with the discontinuity from the southern.

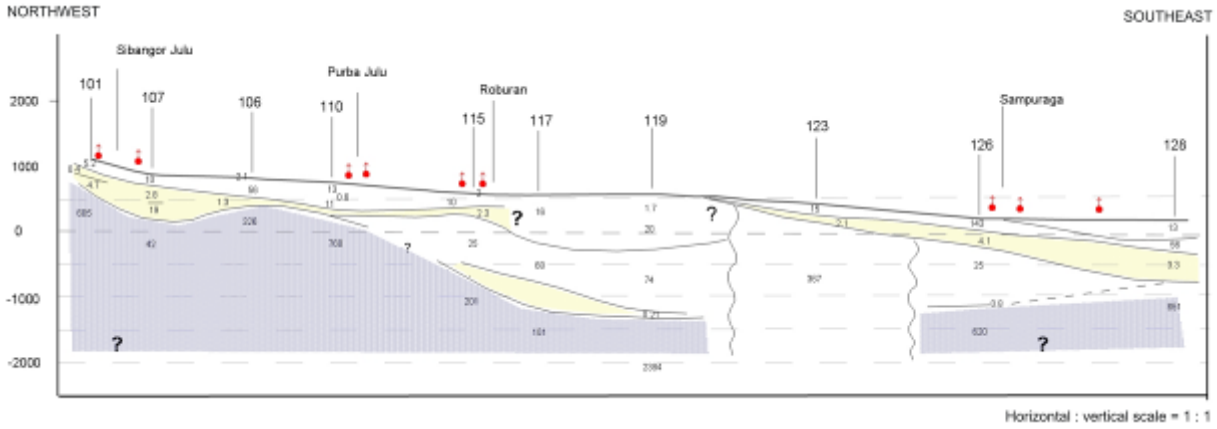

Figure 8: Longitudinal section of resistivity MT of Sorik Marapi at the norhtwest-Southeast direction

5. PROSPECT AREA

Figure 9 shows the compilation of survey outcome from DC resistivity method, gravity, magnet and MT. The compilation of all geophysical methods at the prospect Sorik Marapi is divided into two prospect zones, the northern prospect zone characterized by group of Sampuraga manifestation and the southern zone characterized by the existence of Roburan manifestation group.

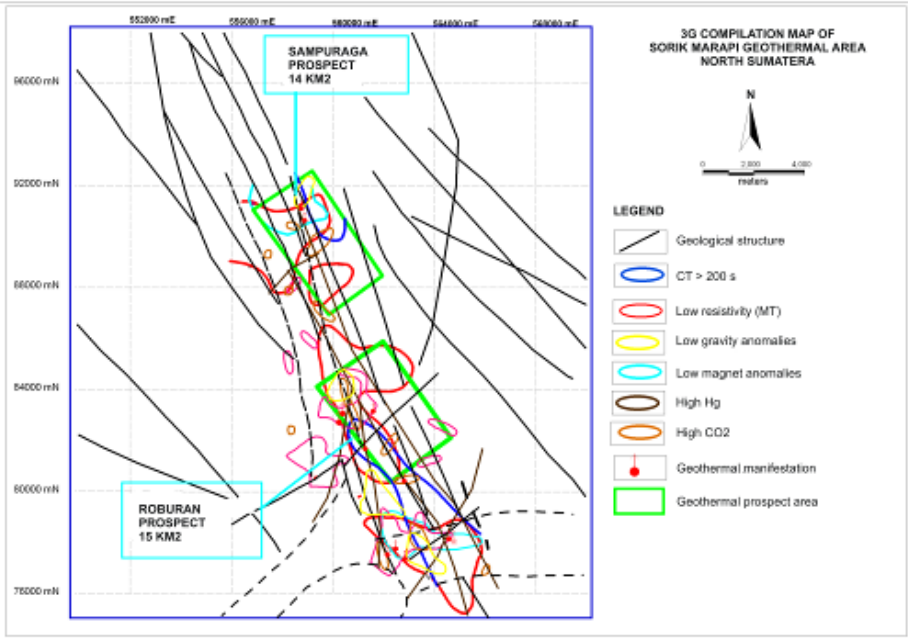

Figure 9: The Integrated Compilation Map of geology geo-chemistry and geophysics to determine the width of prospect area

The existence of prospect Sampuraga zone is supported by the presence of anomaly from DC resistivity, gravity and magnet. The width of this prospect area is about 14 km^2, with the peak of reservoir layer of ± 1200 meter.

The prospect Roburan zone has been delineated clearly from MT method (Conductance Map), DC resistivity, and gravity. The width of geothermal prospect Roburan area is about 15 km^2, with the top reservoir is at the depth of 600 meter (shallow reservoir).

6. SUBSURFACE GEOLOGY

The subsurface geological data have been collected from exploration drilling, temperature slope drilling. At the geothermal areas of Sorik Marapi – Roburan - Sampuraga have been carried out three temperature-slope wells, those are SMR-1, SMR-2, and SMR-3.

6.1 Logging temperature

The result of logging temperature from the three temperature-slope well holes show the relatively nearly same outcome, with the temperature-slope values of SMR-1 and SMR-3 reached at 2,61^{o}C/10m, whereas the temperature-slope value of SMR-2 reached at

2,27°C/10m. Temperature at the well basement of SMR – 1 there is the temperature of 67,58°C, the well of SMR-2 it has been recorded at 73,43°C, while the well SMR-3 the temperature at well basement has been recorded at 92°C where the depth from 76m to 250m, it has occurred an hot water outpouring, temperature to the surface is the range of 39 – 42ºC, with the discharge of ± 1350 lpm.

The well SMR-1 is located at the prospect Sibangor area, SMR-2 at the prospect Roburan area, and SMR-3 is located at the prospect Sampuraga area. From the data of logging drilling SMR-1 there is a loss circulation zone indicating the permeable zone.

6.2 Lithology and Alteration Mineral

Lithology of the well SMR-1 is divided into 3 units consisting of andesite, breccia volcanic and pyroclastic. The pH value of rock SMR-1 is in the range of 3,6 – 8,1 at the depth of 5 – 15 m, 75 – 80 m, and at 149 m relatively acid (pH 3,6). The alteration minerals founded at SMR-1 are clay, chlorite, silica, pyrite, carbonate and ore minerals, and weak-moderate alteration level.

The result of water sample analysis in the well indicates that the water type is neutral water with the type Na-Cl-HCO3-SO4.

Lithology of the well SMR-2 is divided into 3 units consisting of breccia, volcanic breccia andesite and andesite. The pH value of rock SMR-2 is relatively normal in the range of 6, 9 – 7, 1. The alteration minerals founded at SMR-2 are clay, chlorite, carbonate, epidotic, silica and oxide minerals of moderate-strong alteration level.

The result of water sample analysis in the well indicates that the water type is neutral water with the type Na-Cl-HCO3-SO4.

Lithology of the well SMR-3 is divided into 4 units consisting of breccia volcanic breccia, tuffed sand, breccia andesite, and andesite. The pH value of rock SMR-3 is in the range of 5, 8 – 7,2. The alteration minerals founded at SMR-3 are clay, oxide, pyrite, chlorite, and silica of moderate-weak alteration level.

The result of water sample analysis in the well indicates that the water type is neutral water with the type Na-Cl-HCO3-SO4.

The presence of secondary minerals at the well arranging lithology indicates that there is a hydrothermal fluid activity in this area. The alteration level at the well SMR-3 is more intensive than that of other wells dominated by non-altered fresh rock and weak altered rock.

The alteration intensity at the well SMR-2 is in the levels of middle to strong, consisting of two alteration zones, those are argillic and propylenic zones. The argillic zone has been structured by secondary mineral, secondary clay with the temperature span of the formation is in the range of 35 – 150°C, the characteristic of low-pH fluid (acid) being at the depth in the range of 0 to 69 m and the propylenic zone characterized by the presence of epidotic, chlorite and serisit minerals has temperature span of formation is in the range of 120 – 320°C with the fluid characteristic is neutral being at depth span in the range of 69 to 225 m.

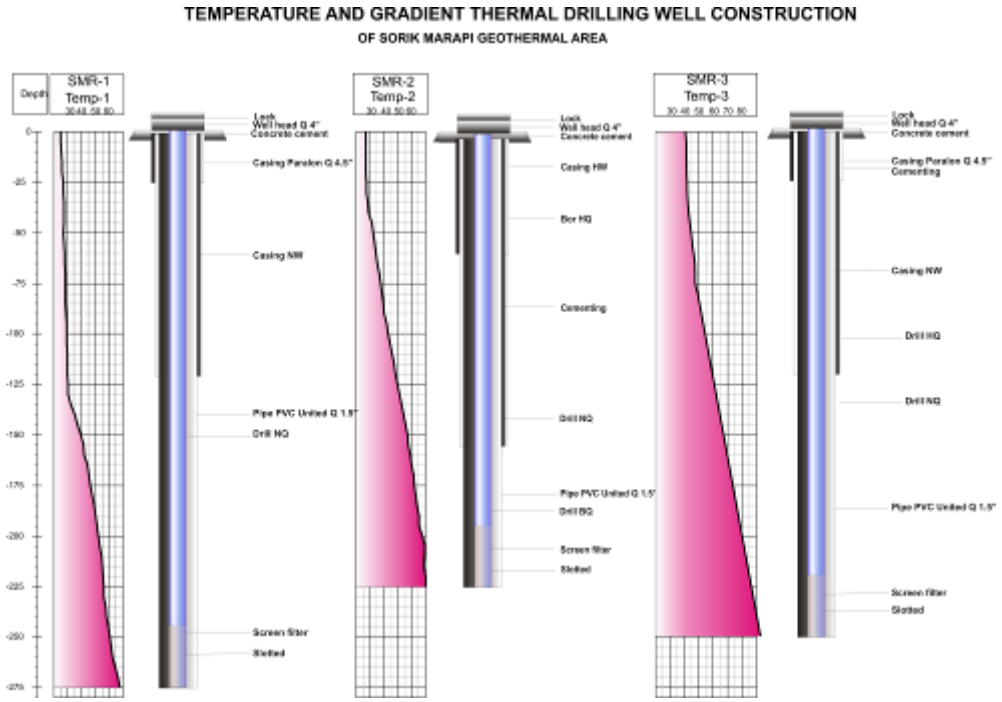

Figure 10: logging temperature and pressure of the wells SMR-1, SMR-2, and SMR-3

7. GEOTHERMAL SYSTEM

7.1 Cap rock

Based on the evaluation result of the data of geology and geo-chemistry, and geophysics as well as temperature-slope drilling, geothermal system of Sorik Marapi is a geothermal system formed at the volcanic complex environment. Cap rock having water-nonpass or waterproof (impermeable) is in the form of volcanic rock of Sorik Marapi that has altered with the alteration in the forms of clay, chlorite, silica, pyrite, carbonate epidotic, silica, oxide and core minerals with the moderate-to-strong change levels.

The cap rock in the form of this clay cap restrains hydrothermal fluid being in reservoir layer.

Based on the interpretation of MT method, the rock functioning as this cap layer is shown in the form of conductive layer (< 10 ohm-m), predicted to possess the thick in the range of 200 - 500 m at the prospect Sibangor area, 200 - 400 m at the prospect Roburan area, and at the prospect Sampuraga area.

The conductive layers are predicted to possess the thick in the range of 200 - 300 m with the depth of average 200 m.

7.2 Reservoir

The geothermal reservoir layers of Sorik Marapi – Roburan - Sampuraga areas are predicted to be existing under the prospect Roburan and Sampuraga areas restricted by footwall of Gadis fault at the northwest– southeast.

The Gadis fault is an extension segment of the fresh zone of Sumatera fault zone having a potency to form a container subsurface that is nest and having fluid-pass power, it can store hot fluids well as having temperature and pressure from geothermal system of Sorik Marapi.

Reservoir is predicted to be a two-phase water system located at tertiary volcanic rock with the peak at the depth of >1000 m. The prospect Roburan and Sampuraga areas have reservoirs separated by big structures as shown in the data of MT.

The reservoir of prospect Sampuraga is predicted to dominate by water (water dominated system) with the reservoir peak is in the depth of ± 1200 m, while the prospect Roburan area is predicted to possess a two-phase system with the reservoir peak is in the depth of 900 to 1000 m. in addition, the prospect Roburan area is interpreted to possess a shallow reservoir in the depth of 600 m as seen at longitudinal section MT that directed at northwest – southeast cutting cross the location of Roburan manifestation.

This Interpretation is also supported by geo-chemistry data where the hot water of Roburan Dolok has ratios of Na/Ca (0.9) and Cl/HCO3 that are small indicating the shallow reservoir temperature is low (A. Nasution, S. Primulyana, 2007).

The reservoir forming Lithology is expected to be undifferentiated volcanic rock in tertiary age that has also a physic characteristic of rock that largely contain pores (porous) primarily in both breccia tuff and breccia laharic units.

7.3 Basement

The basement rock underlining the geothermal system is based on regional geological data and supported by MT, at the geothermal areas of Sorik Marapi - Roburan - Sampuraga are predicted are metamorphic rocks. Kuantan Formation, Meta limestone and Meta volcanic.

This rock is predicted to be in the range of > 2000 m subsurface, overland in conformably by the younger rock over it.

7.4 Heat Source

Several geological forms that may become heat sources, firstly in the form of hot residue of magmatic chamber associated with young volcanic cone, secondly it can be in the form of young intrusion rock body that is not disclosed at the surface.

Geologically there are several areas at the geothermal areas of Sorik Marapi - Roburan - Sampuraga enabling to become heat source, that is hot residue of magmatic chamber of Volcano Sorik Marapi whose the product has quarter age and is an active volcanic type A that has already certain to still possess a good hot as heat source for geothermal system in this area.

Meanwhile the deistic young intrusion rock body predicted as heat source at the prospect Sampuraga area (The Report of Integrated Survey Outcomes of Geothermal Area of Sampuraga, PMG, 2007) is still not yet adequate convinced by didn't supported by gravity data that didn't indicating the presence of positive anomaly in the area, and there is no the age determining data for the rock predicted as the heat source.

So the approach of rationale to predict the heat source at the prospect Sampuraga area tends to be still associated with the hot from magmatic chamber of Volcano Sorik Marapi, supported by the concept that the group of Sampuraga manifestation is outflow of geothermal system of Sorik Marapi as shown in the Figure of conceptual model.

7.5 Geothermal Fluid

The Geothermal areas of Sorik Marapi – Roburan - Sampuraga is in the complex volcanic depression zone of Volcano Sorik Marapi with many geological structures (solid and fault) developing to make this area has capacity to pass the surface water (meteoric water) to subsurface.

A part of the meteoric water then interacts with magmatic fluid and volcanic gases coming from magmatic body and occurred hot propagation yielding the hot fluid.

From geo-science evaluation of geothermal areas of Sorik Marapi - Roburan - Sampuraga, the fluid supply controlling the hot spring of Sampuraga is in the type of chloride - bicarbonate indicating the characteristic of outflow zone of the geothermal system of Sorik Marapi. With the high ratios of Na/Ca and Cl/SO4, it indicates outflow of reservoir at the boiling condition (+/- 300 °C) which in the course to the surface it undergoes a mixing with shallow ground water (A. Nasution, S. Primulyana, ITB, 2007).

The boron concentration of crater water and hot water of Sampuraga is sufficiently high (18.33-24.61ppm) it has been expected that the level of the rock solubility occurs at high temperature, particularly sedimentary deposition and reservoir is approximated to dominate by hot water (water dominated system) supported by the high discharge of hot spring as the geothermal manifestation.

Whereas with the emergence of fumaroles and the chloride - sulphate typed at the group of Roburan manifestation indicates that the area as upflow zone of the geothermal system of Sorik Marapi.

Meanwhile the bicarbonate –typed hot water of Roburan Dolok -2 with pH neutral, indicates that gas CO2 rising up to the surface contacts to the shallow ground water (A. Nasution, S. Primulyana, 2007).

In addition to the location that does not too far from the eruption centre of Volcano Sorik Marapi, the high content of SO4 and Cl as well as the acid pH in the group of Sibangor manifestation supports the rationale that the manifestation in this area is more associated with volcanic system of the geothermal system itself.

7.6 Hydrogeology

Hydrogeology component of the geothermal areas of Sorik Marapi – Roburan - Sampuraga is general divided into a recharged area of the place where the meteoric water penetration occurred at the earth surface, and discharged area, the place where the discharged area occurs at the surface and subsurface.

The recharged area is located at the high-elevated areas at the hills stretching to northwest – southeast at the western of this area, while emerged area is located at the low-elevated area, slope bend and in the form of levelling primarily at the depression zone area of Panyabungan located at Sampuraga region to the north. It is these two areas holding an important role in the hydrologic cycle in this area.

8. CONCLUSION

Vertical longitudinal section as shown in the conceptual model indicates clearly the effect of subsurface temperature for spreading permeability of the geothermal reservoir of Sorik Marapi.

Isothermal pattern in Figure 11 is associated with permeability and impermeability of the elements covered in the conceptual model.

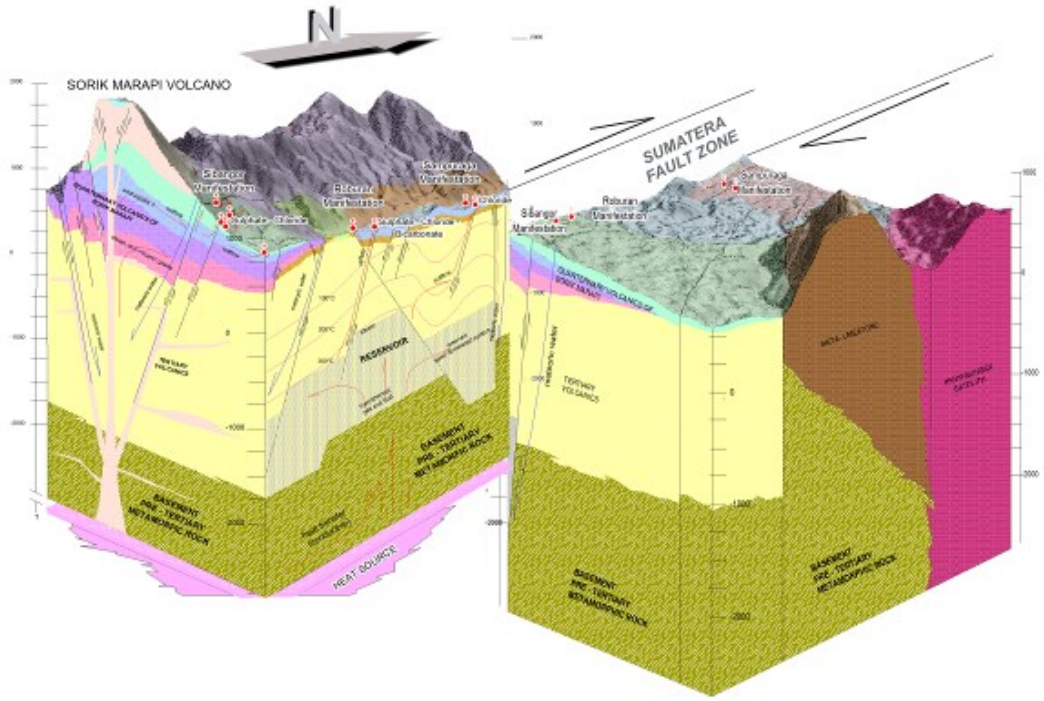

Figure 11: Conceptual model of prospect Sorik Marapi-Roburan and Sampuraga

In the geothermal system, thermal pressure causes the fluid moving up; in the isothermal permeable zone it will shift according to the fluid rises up to the surface.

The up flow zone seen from isothermal line is under group of Roburan manifestation with the pattern protruding vertical up as a result of the increase of spreading local temperature of the area, while the outflow area is under group of Sampuraga manifestation with the pattern protruding horizontal indicating a figure of hot fluid flow moving horizontally in line with the decrease of temperature.

Reservoir of Roburan prospect area is estimated to have two phase system with temperature of 270 - 290°C thickness of 1000 m where its top at 900 to 1000 m and shallow reservoir at depth of 600 m. Reservoir of Sampuraga prospect area is estimated to have water dominated system with temperature of 220 - 230°C thickness of 800 m where its top at 1200 m. Heat sources is interpreted as cooling magma which probably associated to the young volcano of Sorik Marapi