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3D Natural State Modeling of Wapsalit Geothermal Area, Maluku, Indonesia

Rizqi Mahfudz Prasetyo[1]*, Ulyl Aidi Al-Abshor[1], Allen Haryanto Lukmana[1]

[1]Faculty of Mineral Technology, UPN "Veteran" Yogyakarta, Indonesia

*rizqimp5@gmail.com

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ABSTRACT

Wapsalit geothermal area is located in Buru Island, Wae Apo District, Buru Region, Province of Maluku, Indonesia. Based on a previous study, Wapsalit is estimated to have the potential of 45 MWe in resources and 25 MWe in reserves. Wapsalit area is estimated to have a liquid dominated reservoir with a temperature between 218°C – 247°C.

An early natural state model of the Wapsalit reservoir was developed to identify the initial condition of the undisturbed reservoir. The model is built using the TOUGH2 simulator. Model structure, initial condition, and boundary condition are defined by the geological, geophysical, and geochemical study, as there is no deep hole drilled yet.

The model size is 5 km x 4 km and 3500 m in thickness. It has 4032 of cell blocks with the roughest cell size being 500 m x 500 m and the finest being 250 m x 250 m. Cell blocks' thickness varies from 50 m to 450 m depending on the specified region. The model is validated by matching the model temperature to the reservoir temperature estimation using geothermometer and temperature gradient survey, which shows a good enough match.

1. INTRODUCTION

Wapsalit area is located in Buru Island, Wae Apo District, Buru Region, Province of Maluku, Indonesia. Electricity demands in this area are currently supplied by a diesel-fuel power plant. As the electricity demand increases and the population grows, the plant is unable to power the entire area. Therefore, an additional plant is needed to fulfill the electricity needs in the area.

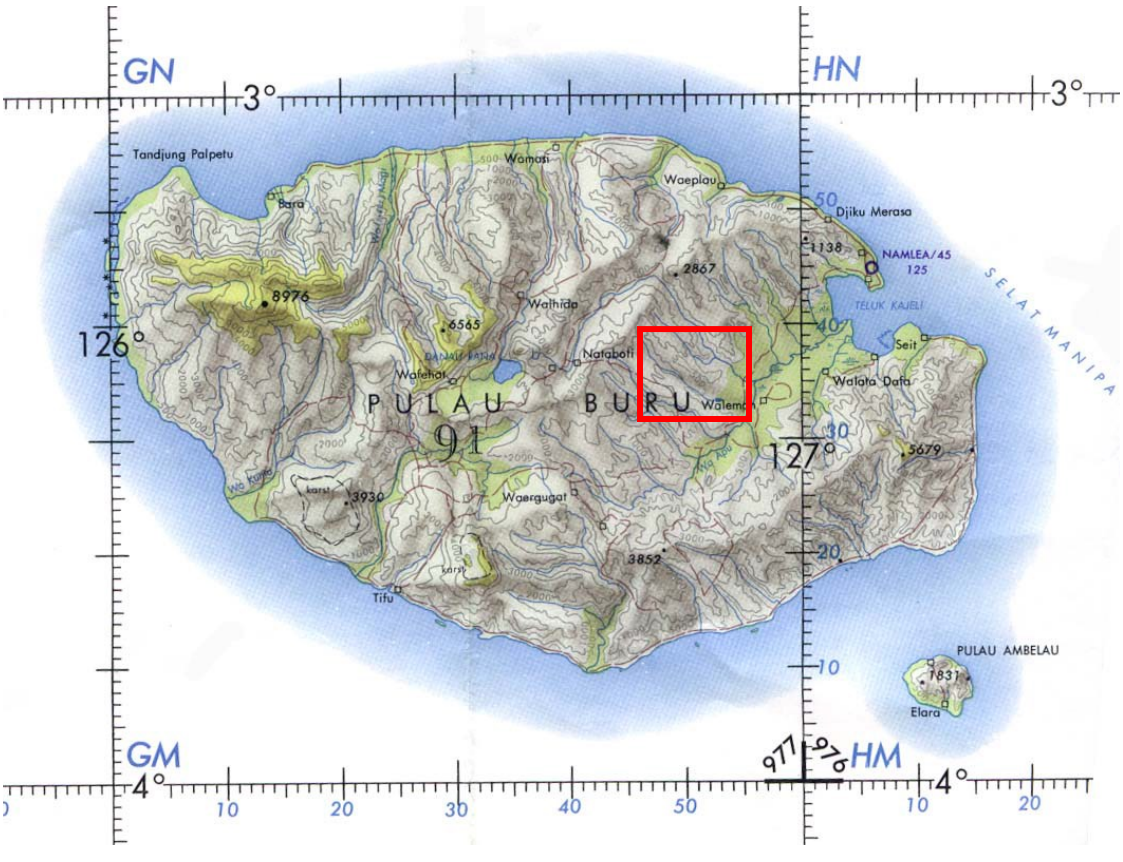

Figure 1: Wapsalit geothermal area location (Zarkasyi et al., 2007).

Wapsalit has a geothermal potential of 45 MWe resources and 25 MWe reserves. Wapsalit Geothermal Area is expressed in SK No. 8084K/30/MEM/2016, which is estimated to have an area of 6,038 ha (MEMR, 2017). Wapsalit is estimated as a water dominated reservoir (Idral, 2010). Wapsalit is a unique geothermal area as it is not a product of post volcanic activity, but a non-volcanic area, which magma intrusion underneath is estimated to exist.

Numerical modelling is a reliable technique to analyze the initial & unexploited condition of the reservoir and also to predict the reservoir production performance in the future. Usually, a numerical model is built using geoscience data (geology, geophysics, geochemistry, hydrology) and also well data (DiPippo, 2012).

On the early exploration stage, only geoscience data is obtained since no borehole has been drilled yet. A natural state Wapsalit area numerical model is built based on geoscience data. The model is validated by matching model temperature to reservoir temperature estimations using a geothermometer and temperature gradient survey.

The natural state model or static modelling shows the initial condition of the reservoir before any production. The natural state model can be used for resource estimation and assessment and also as reference for future modelling (Axelsson, 2013). However, some uncertainties remain in this model since no petrophysical and rock thermodynamics data such as porosity, density or rock heat capacity is available. These uncertain parameters are variables in potential energy calculation. Therefore, this model may be inaccurate for the potential energy assessment. Unless the Monte-Carlo simulation is applied.

2. GEOSCIENCES DATA

2.1 Geological Data

According to The Geological Map of Wapsalit Geothermal Area (Sulaeman, et al., 2007), there are four major lithologies which construct the area. They are metamorphic rock, clay rock, river sediments, and alluvial units. The geological structures in the area are dominated by northwest – southeast faults and northeast – southwest faults. They are Wapsalit fault, Waetina Fault, Resun Fault, Waekadang Fault, Debu Fault, and Waemetar Complex Fault.

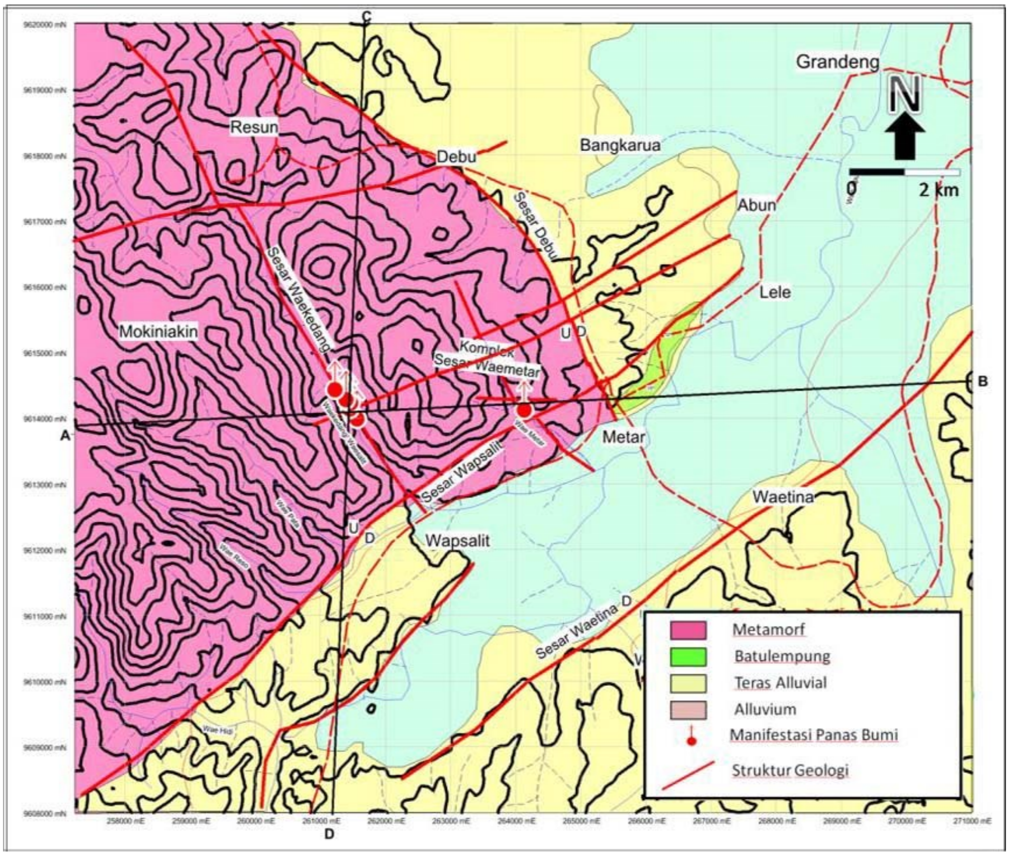

Figure 2: Geological Map of Wapsalit Geothermal Area (Sulaeman et al., 2007).

The prospect location is indicated by the appearance of surface manifestations (hot springs, warm ground, and steam vents), several hydrothermal alterations (muscovite, dickite, kaolinite, halloysite, and illite), sulphur and salt deposits in the center of the map in metamorphic rocks area (Nurhadi & Sulaeman, 2010).

2.2 Geophysical Data

Geophysical surveys are conducted to determine the subsurface feature of the geothermal system. Magnetotelluric (MT) survey is one of several methods to determine resistivity distribution that can be interpreted as geothermal systems components, caprock, reservoir rock, heat source, and even structures (Takodama et al., 2017). Therefore, the latest MT survey by Takodama et al. (2017) is used as the main reference in building Wapsalit numerical model.

According to the resistivity distribution map at depth 2750 m, there are two areas which are interpreted as heat sources. The main heat source is in the centre of the map underneath the Wapsalit Hot springs, and the other one is adjacent to Waemetar Hot spring.

This statement is supported by gravity and magnetic surveys which estimated that there are two heat sources in the Wapsalit area in the form of intrusive rock (Sumardi et al., 2007; Idral,2010). There is low resistivity region around the manifestation with Wapsalit being shallower than the northeast area (Kholid, M. et al., 2015).

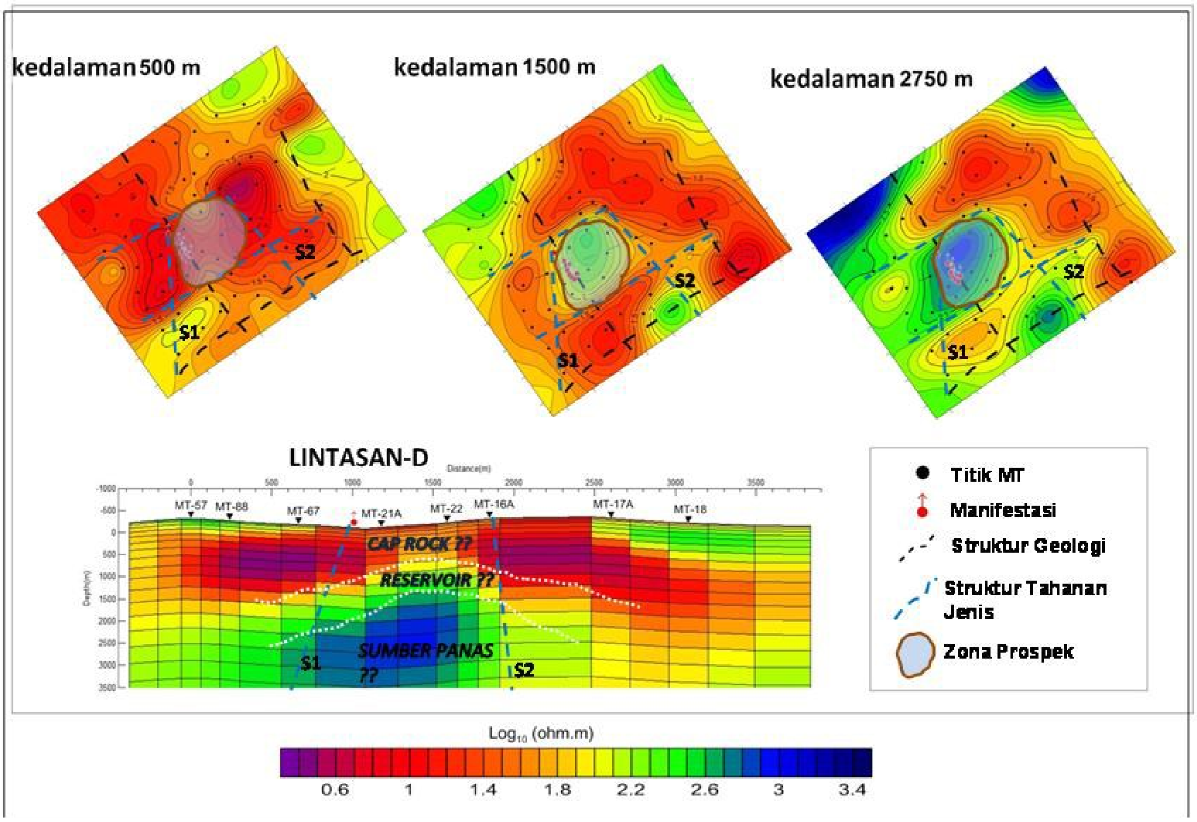

Figure 3: Resistivity distribution in Wapsalit (Takodama, et al., 2007).

2.3 Geochemistry Data

There are 4 hot springs identified in Wapsalit Area. They are Wapsalit-1, Wapsalit-2 Wapsalit-3, and Waemetar hot spring. The hot springs' pH ranges from 7.0 to 9.50. The temperature ranges from 99°C to 102°C. Chemical analysis indicates that all the hot springs have HCO_3. Table 1 below shows the chemical composition and properties of hot springs in Wapsalit Area.

Table 1. Chemical Composition of Wapsalit Hot Springs (Nurhadi and Sulaeman, 2010).

Parameter	Wapsalit-1	Wapsalit-2	Wapsalit-3	Waemetar
pH	9.4	9.1	9.3	7.2
Na	1234	1216	1101	686
K	75.2	76.8	60	28.8
Li	6.8	6.9	5.2	2.8
Ca	0	0	0	16.8
Mg	0.02	0.02	0.01	3.41
Fe	0.02	0.03	0.03	0.21
Al	0	0	0	0
CO_3	637.16	407.55	499.19	0
As	0.2	0.1	0	0
NH_4	2.73	5.64	4.73	9.09
HCO_3	1540.08	2001.79	1532.35	1816.64
Cl	228.67	232.19	182.34	105.54
SO_4	40	40	50	1
B	33.58	35.08	25.51	15.28
F	2	3	1	1
SiO_2	328.24	323.87	248.15	73.46
Conductivity	4500	4360	4300	2330

According to Table 1 above, chemical analysis is made to identify the chemical properties and the source of the water. Triangle ternary plots of Wapsalit hotsprings are shown in Figure 4 below.

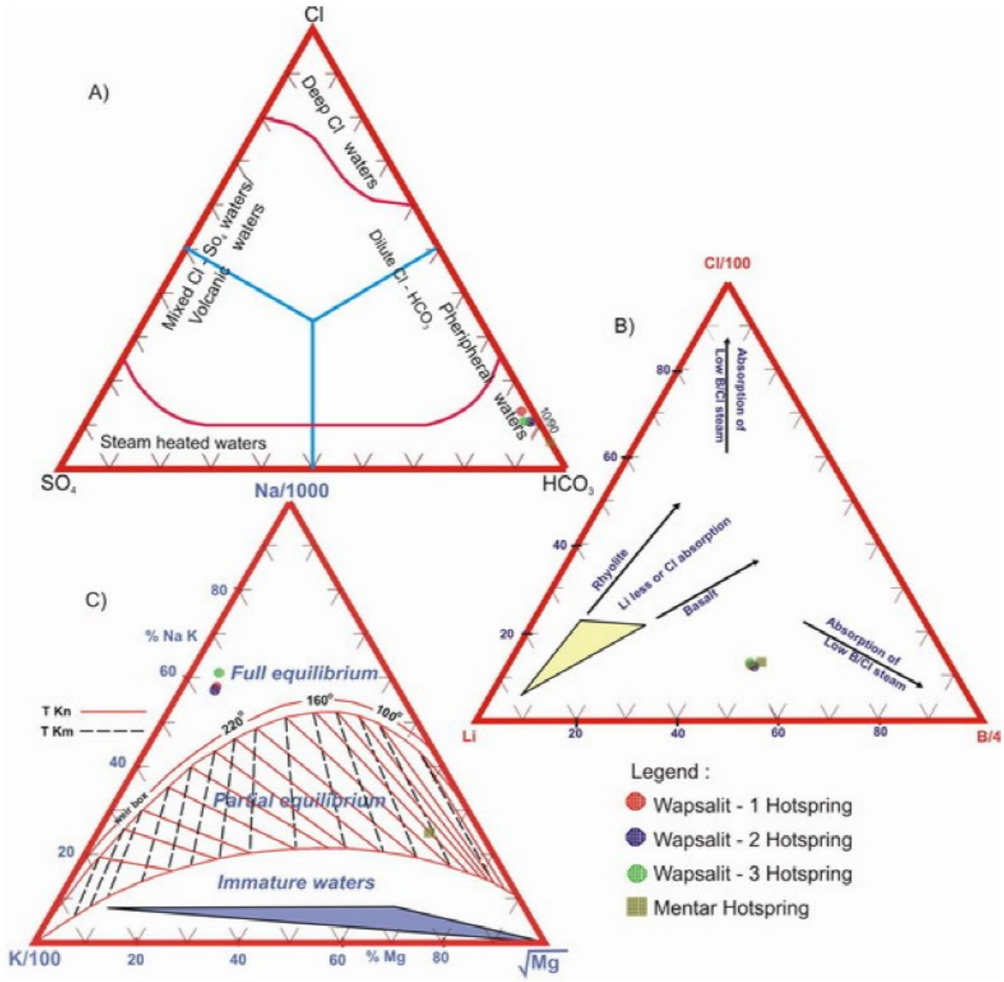

Figure 4: Chemical Analysis of Wapsalit Hot Springs (Nurhadi and Sulaeman, 2010).

Based on the geochemical analysis, all the springs are HCO_3 types under the influence of meteoric water. Na-K-Mg plot shows that the springs are in full equilibrium region and come from deep water in the reservoir. Cl-Li-B plot shows that the springs are in the center triangle, which means they come from the same system (Nurhadi and Sulaeman, 2010).

One of the main purposes of the geochemical survey is to determine the reservoir temperature using ion contents in surface manifestations; the tool to measure this is called geothermometer. Several researchers have measured the geothermometer of Wapsalit potential with calculations results in an average of 235°C (Sulaeman et al., 2007; Zarkasyi et al., 2007;2010; MEMR, 2017).

3. METHODOLOGY

The numerical model is built based on geoscience data and the conceptual model of the system. The 3D grid-blocks numerical model is created using TOUGH2 simulator. Then, the boundary and initial conditions are set to the model. Then, the 3D numerical model is simulated for infinite time until it reaches the steady-state condition. Usually, it takes more than 1 million years (3.1E13) to reach steady-state condition (Vereina, 2005). Wapsalit model reaches natural state at 1.9E16 s or 612 million years. The model is validated by matching model temperature to reservoir temperature based on geothermometer. If the model temperature and geothermometer temperature does not show a good match the material properties need to be calibrated until it shows a good match (trial and error).

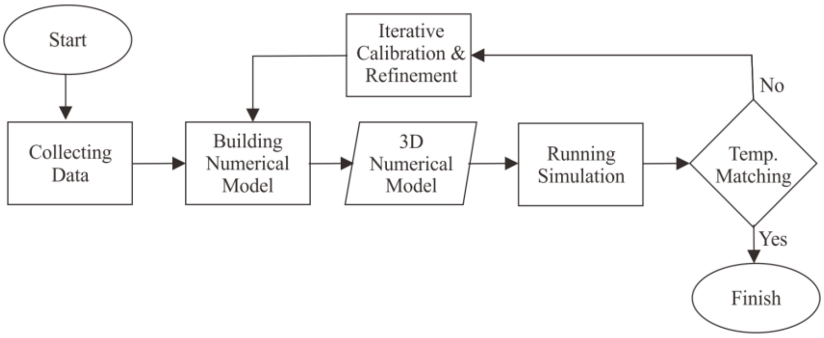

Figure 5: Research Flowchart.

4. MODEL DESCRIPTIONS

4.1 Grid System

The model has size 5,000 m x 4,000 m, and 3,500 m thickness. It has 4032 of rectangular cell blocks with the roughest cell size is 500 m x 500 m and the finest is 250 m x 250 m. It has 15 layers thickness varies from 50 m to 450 m depending on the region. Thickness each layer are shown in the Table 2 below.

Table 2. Model Thickness and Material.

Layer	Thickness/Elevation Profile	Material
ATM	450	Atmosphere
L1	50	Groundwater
L2	100	Groundwater
L3	200	Groundwater, Cap Rock
L4	200	Groundwater, Cap Rock
L5	250	Caprock
L6	250	Caprock
L7	200	Caprock, Reservoir
L8	200	Caprock, Reservoir
L9	200	Reservoir
L10	200	Reservoir
L11	200	Reservoir
L12	200	Reservoir
L13	200	Reservoir
L14	350	Reservoir
L15	250	Reservoir, Heat Source

Layer thicknesses are defined based on the MT survey of the research area. The thick layer (450 m) is assigned for atmosphere material to represent the huge volume of it. The thin layer (50 m) is assigned to represent the thin layer of groundwater in the area. The medium thickness layers are assigned for reservoir and caprock to increase the accuracy of later calibration and material modification.

Four main faults in the area are built in the model to represent the actual condition, they are Waekadang Fault, Wapsalit Fault, and two faults from Waemetar Complex Fault. The faults have NW-SE and NE-SW direction. Other than that, the surface manifestations in the Wapsalit area are assigned to the model. They are Wapsalit-1, Wapsalit-2, Wapsalit-3, and Waemetar hot spring. In the model, these hot springs are presented as a well model which has a constant rate based on field data.

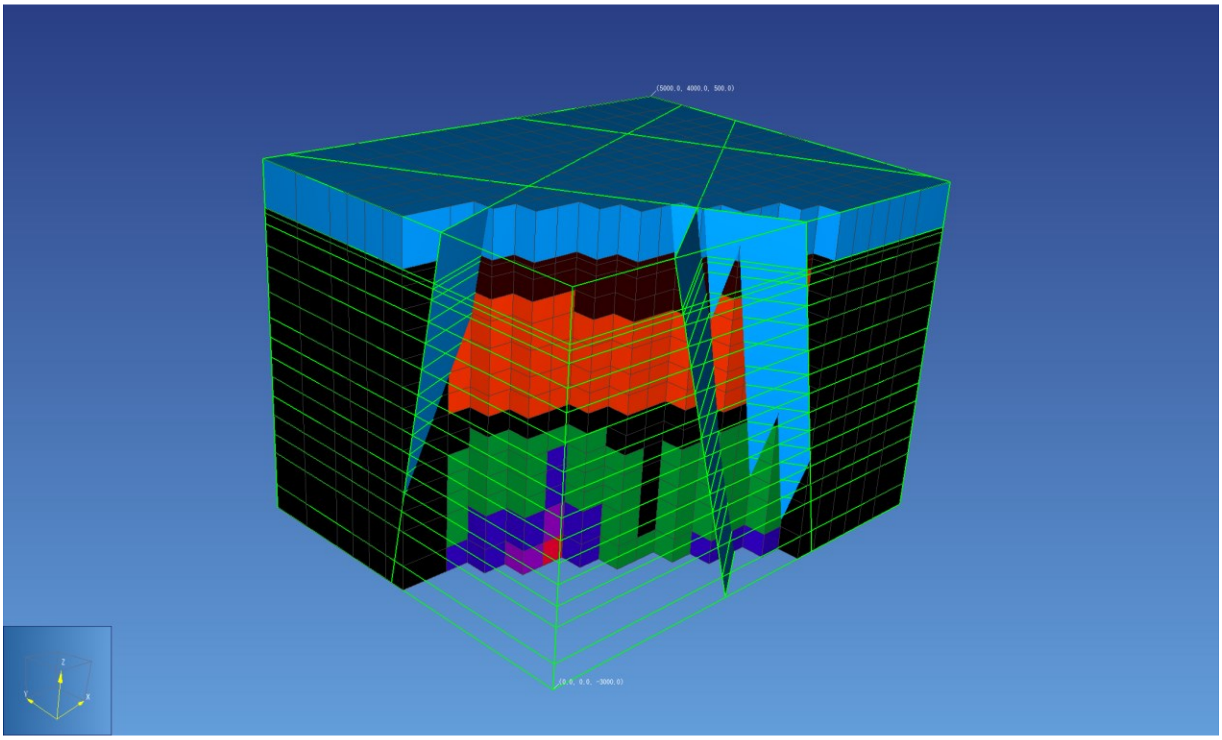

Figure 5: 3D Numerical Model of Wapsalit Area.

4.2 Material Properties

The porosity of the reservoir is assigned based on the assumption from the Indonesian National Standard. While the reservoir's permeabilities are estimated by initial assumption and later calibration. Other material's porosity values are assigned by the initial assumption. Atmosphere are set to have unlimited porosity and permeability, then it is assigned to have porosity value near 1.0 and permeability 1,00E-12 m^2. The side boundary is made to isolate the model, then it is assigned to have low porosity and permeability. The fault is estimated to have high porosity and permeability as there are some surface manifestation which is controlled by the existence of the faults. Material properties used in this model are shown in Table 3 below.

Table 3. Material Properties.

Material	Color	Density (kg/m^3)	Porosity (fraction)	Permeability (m^2)	
				x,y	z
ATM		2,600	0.99	1,00E-12	1,00E-12
GRWTR		2,400	0.1	1,00E-15	5,00E-16
CAPR		2,500	0.1	1,00E-18	5,00E-19
SDBDR		2,600	0.02	1,00E-19	1,00E-19
RES1		2,550	0.1	2,00E-14	1,00E-14
RES2		2,600	0.1	3,00E-13	2,00E-13
RES3		2,600	0.1	1,00E-14	1,00E-14
HEAT		2,600	0.1	1,00E-13	1,00E-13
FAULT		2,600	0.3	1,00E-13	5,00E-13

The range of permeability calibration of reservoir material is estimated based on the estimated natural condition of lithologies in the area. The lithology constructing the area is dominated by old and faulted metamorphic rocks. Metamorphic rocks have three types of porosity; they are intracrystalline porosity, porosity due to weathering, and porosity due to fracturing and faulting (Toth, 2009). Fresh metamorphic rocks usually have very low porosity and permeability, but chemical and physical weathering may increase these values. Since metamorphic rocks in the area is old, faulted, and heated, it is estimated if the rocks have high hydraulic conductivity, as well as porosity and permeability.

4.3 Initial and Boundary Conditions

Initial pressure and conditions assigned to the model are normal temperature and hydrostatic pressure gradients. They are 9,798 0.05 °C for temperature and Pa/m for pressure.

The boundary conditions of the model are assigned to the top, bottom, and side of the model. The top boundary is assumed to have an atmospheric condition with a pressure of 1.0135 Pa and temperature of 25°C. The atmosphere layer volume area is assigned to 1E+20 to maintain the condition that is not affected by the heat source below. The bottom boundary of heat source has 300 bar pressure, 300 °C of temperature and 1E+38 volume factor. The pressure is estimated based on hydrostatic pressure in the bottom of the model. The high-volume factor of the heat source is to represent the intrusive magma which has high influence to the model. It also has fluid recharge of 5 kg/s and enthalpy 1,06149E06 J/kg. The side boundary assigned has very low permeability to ensure no heat and fluid in or out.

5. NATURAL STATE CONDITION

Natural state condition is the undisturbed condition of geothermal system before any production. Natural state validation in this model done by temperature matching between the model temperature and geothermometer estimation.

5.1 Temperature Matching

Since there is no borehole drilled yet in the research area, synthetic well named WELL-1 was built in the model for pressure and temperature measurements. WELL-1 was placed in the reservoir zone with total depth -2000 m. Model validation is done by temperature matching between the model temperature and geothermometer estimation. The temperature between the surface and the reservoir is interpolated based on linear equation. The temperature matching result can be seen in Figure 6.

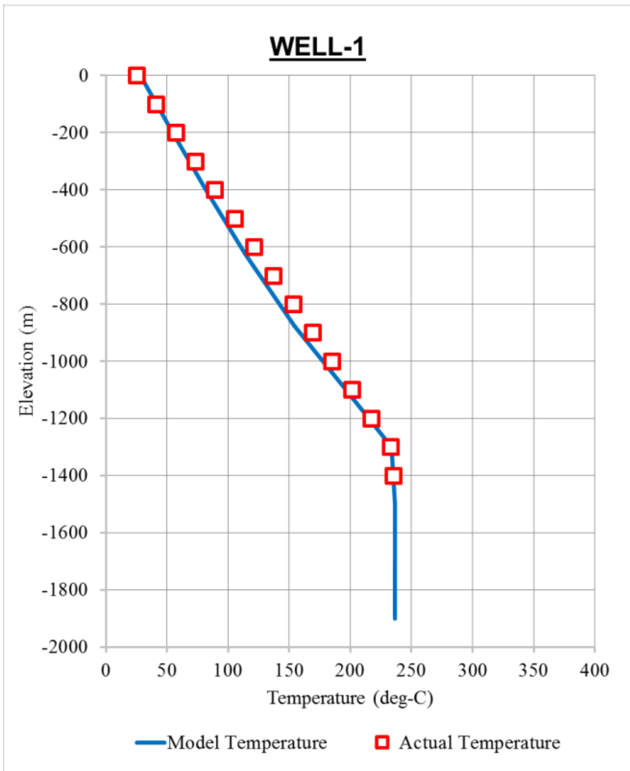

Figure 6: Well Temperature Matching Wapsalit Area.

The model pressure shows a good match to the interpolated-geothermometer profile of 235 °C. The model has a high geothermal gradient from surface to the reservoir which indicates if the heat propagation is through conductive system due to low porosity and permeability. The low-thermal gradient in the reservoir and beneath indicates if the heat is transferred through fluid flow along the pore space as the reservoir has high permeability.

The high permeability in the reservoir zone is identified to be a convective thermal system (low thermal gradient) since geothermal fluid is filling the pore space in the reservoir. While low permeability in caprock and beyond is identified to be a conductive thermal system (high thermal gradient).

5.2 Heat and Mass Flow

The heat and mass flow inside the model controlled by reservoir permeability distribution. The heat flow can be described by crossing the reservoir in x, y , and z-direction.

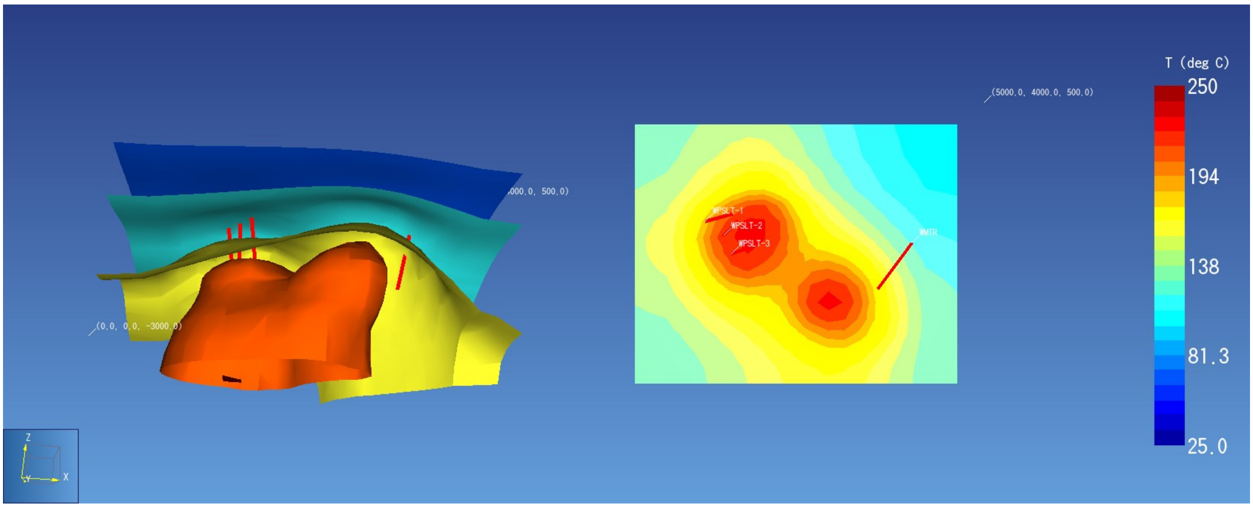

Figure 7: Cross section Wapsalit model in 3D (left) z-direction (right).

According to Figure 7, the heat inside the reservoir is flowing from the bottom heat sources and upward into the permeable zone. The model simulation result is analog to the MT survey which indicates two heat sources and a reservoir zone. Both heat sources are ejecting amount of mass and heat upward so that two heat zone are formed, one in the center and the other on the bottom-east side of the model.

The fluid mass flows from the heat source into the upper part of the model reservoir. The mass influx to the model is estimated by trial and error, since there is no certain value of mass influx or natural recharge which is very complex. However, based on the simulation, 5 kg/s of mass influx is enough to supply fluid into the system as the model manifestation discharge rates are equal to actual condition. The high mass influx are detected in the manifestation zone near the Waekadang and Waemetar fault joint. It is quite challenging to model the manifestation flow rate into the surface as the actual condition, while the Wapsalit 1, 2, and 3 hot springs location are adjacent to each other. Therefore, a fault is built and crosses all the sources of surface manifestation. High porosity and permeability of fault influence the discharge rate of surface manifestations since fluid in the reservoir is likely to flow into a more permeable material.

5.3 Reservoir Characterization

The entire reservoir zone is saturated by water and no steam zone is formed. The reservoir has two heat sources from intrusive rocks in center and bottom-east areas. Connections between the two systems is unknown yet. However, the complex fault system and the fault density are indicating a high permability zone that cuts across the two reservoir. It may be the main factor that can make the permeability of the system connected to each other, as well as to the geothermal system.

6. CONCLUSIONS

1. The early natural state model of the liquid-dominated reservoir of Wapsalit geothermal area has been developed based on geosciences data since limited petrophysical data is available. Uncertainties in the petrophysical properties of the reservoir may affect the reserve assessment.

2. The model is validated by matching the model temperature to geothermometer calculation with linear interpolation after being simulated for 612 million years. The reservoir temperature reaches 235°C and shows a good match.

3. The high permeability in the reservoir zone is identified to be a convective thermal system (low thermal gradient) since geothermal fluid is filling the pore space in the reservoir. While low permeability in caprock and beyond is identified to be a conductive thermal system (high thermal gradient).

4. The model has two heat sources reservoir systems, while the connection between these systems is unknown. But, considering the appearance of hot spring manifestation in different sides of the area, these systems may be connected by permeable faults.

5. The mass influx to the model is assigned to 5 kg/s. The value is considered as enough fluid to supply the system since the model manifestation discharge rates are equal to the actual condition.

6. Faults in the model contribute to surface manifestation discharge. Fluid in the reservoir is likely to flow into more permeable material while all the surface manifestations are controlled by the fault inside the model.

7. RECOMMENDATIONS

1. The model needs to be updated after well data is taken from any borehole drilling, particularly with actual temperature and pressure data to achieve valid model.

2. Attempt to use fine grid-block size that's less than 200 m x 200 m (the minimum in this model) to build a more representative model.

3. Identify fault properties and assigning a fracture and dual porosity model (MINC).

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