

IDENTIFICATION OF RESERVOIR THICKNESS OF IJEN (GEOTHERMAL PROSPECT AREA, INDONESIA) USING RESISTIVITY METHOD WITH SCHLUMBERGER CONFIGURATION

Akhmad Afandi^{1}, I.G.N.B. Catrawedarma¹, Sukir Maryanto², Ahmad Nadhir², M. B. Zaman³, Nugroho Agung Pambudi⁴

¹ Department of Mechanical Engineering, Politeknik Negeri Banyuwangi, Indonesia; ² Department of Physics, Brawijaya University, Indonesia; ³ Department of Mechanical Engineering, Yudharta University, Indonesia; ⁴ Department of Mechanical Engineering Education, Sebelas Maret University, Indonesia.

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ABSTRACT: This research has been conducted to study geothermal potential in the Ijen area of Banyuwangi - East Java, Indonesia based on the resistivity method with Schlumberger configuration by using a Nanura resistivity meter device, model NRD 22S, and Garmin GPS. This study aims to understand the distribution and the thickness of the reservoir. The results showed that the lithology found in Ijen are tuff, volcanic breccia, lava, sulfur, and a mix of sand and tuff is found with acidic create water. The reservoir is characterized by a low resistivity value of tuff ($10.49 \Omega\text{m} - 89.78 \Omega\text{m}$). The reservoir of Ijen Geothermal area is encountered at point 1 at a depth of 18.04 - 30.44 m with a thickness of 12.4 m and at a depth 63.38 m - 90 m with a thickness 26.62 m, at point 3 at a depth of 73.93 m - 110 m with a thickness of 36.07 m and at point 5 at a depth of 1.91 m - 24.95 m with thickness of 23.04 m and a depth of 32.56 m - 45 m with thickness of 12.44 m. The 3D modeling is done on the resulting lithology, where reservoir which is the main target of this study has a volume of $20.802.000 \text{ m}^3$ which is about 42.7% of the total volume of the 3D model.

Keywords: Reservoir, Geothermal, Ijen, Resistivity.

1. INTRODUCTION

Along with the depletion of energy reserves due to their non-renewable nature, there is a need for continuous studies and explorations to find an alternative energy source that can help supply energy for current electricity demands. To overcome the energy crisis and environmental damage caused by global warming, developing renewable energy are necessary. Each country develops from their potential resources, including Indonesia, which has large geothermal reserves. In Indonesia, the total geothermal potential is estimated at 28,910 GW, drawn from 312 fields located across several islands (Figure 1). Unfortunately, despite having the highest geothermal potential, it draws on less than 5% of this capacity. The total installed capacity is 1533.5 MW and Indonesia is in third ranks after the Philippines and the United States of America for utilization of geothermal [1].

One geothermal prospect location is the Blawan-Ijen in East Java, which has fumaroles associated with the geothermal prospect (Figure 2). The location is in the southeast of the crater at a temperature of about 200°C [2]. Adjacent to the crater, there is a rhyolite dome which has a diameter of 100 m and a thickness of 20 m, which is an activity of fumaroles with temperature

600°C [3] [4] and has a potential of around 270 MW with a work area of 62,620 ha [5].

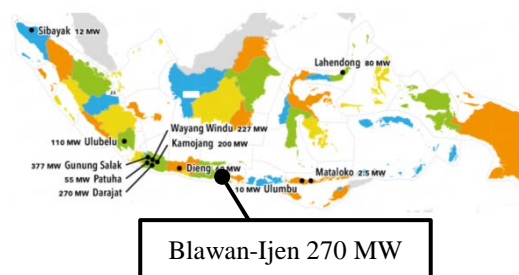


Fig. 1. The geothermal power plant in Indonesia and potential in the Blawan-Ijen (Adapted from[1])

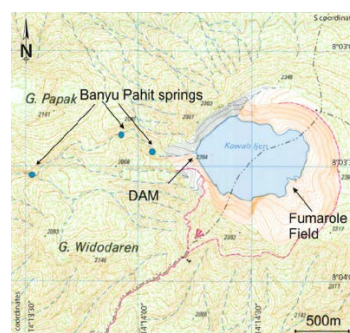


Fig. 2. Fumarole Field in Ijen crater [6].

Development of geothermal utilization takes several stages, including preliminary survey

related to information of the subsurface condition [7]. The stages of investigation and geothermal development related to the classification of potential energy include preliminary exploration such as literature study and field review to obtain geological distribution map and geothermal manifestation (hot water, steaming ground, hot soil, fumaroles, sulfur) that are useful for further investigation guidance, further exploration such as geological, geochemical and geophysical investigations. The latter is exploratory drilling aimed at drilling activities made as an effort to identify detailed inquiry results so as to obtain a geological picture, physical data, and subsurface chemistry as well as fluid quality and quantity [21].

The geothermal system is caused by the inhomogeneous physical properties of the rock subsurface obtained from the measurable anomaly of the surface. Physical parameters often used are a thermal survey, gravity survey, magnetic, electrical conductivity survey and seismic survey [9]. Several research in Ijen has been conducted including temperature, self-potential and multi-scale tomography [10]. However, there has been a lack of observation in the resistivity method aiming to map the direction and the thickness of the reservoir. This is one of the methods used to identify the electrical properties of the rock layers by sending electric currents down to the subsurface [11][12]. The ground surface is considered to be composed of several layers bound by the horizontal boundary plane, as well as the resistivity contrast between the boundary planes of the layers; each of them is homogeneous and isotropic [13]. The geothermal zone shows the high temperature and pressure which result in very low resistivity values [14]. Therefore this study employed the Schlumberger configuration by placing four electrodes into the ground on one stretch to identify the reservoir thickness of Ijen geothermal resources because of the method, it is obtained the value of the potential difference, the strength of the current, value of rock type resistance. The rock type resistance is then processed further so it is obtained the resistance value of each type of rock layer [22]. Thus the subsurface layers can be illustrated by different values of the type resistance of each layer. So this result can be a good description to identify the depth of the reservoir.

2. GEOLOGICAL SETTING

The study area as shown in Fig. 3 is located on the Ijen Muda volcano mountain and it is composed of stuff rocks, volcanic breccia, lava, and sulfur. Tuff is white-gray, smooth, easy to squeeze, and irregularly layered. Volcanic breccia is yellowish gray, gravel-sized to lump-

sized, and has a basal-andesitic component is cornered with a poorly divided mass with a basic mass of stuff. The Lava consists of basal andesite, gray skin, and pyroclastic. Sulfur is yellow, pure, and spread over the crater of Mount Ijen. This rock is sourced from the Ijen Muda and Pajungan volcanoes [15].

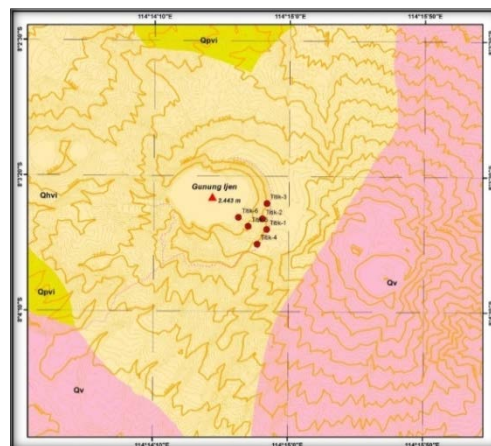


Fig. 3. Geological Map of Research Areas [15].

Ijen volcano is a stratovolcano ride on Merapi volcano. The Ijen volcano body is formed from a loose material that overlaps each other by bedrock. New material will be deposited in a volcano environment every time an eruption occurs. The break between eruptions is the time of formation of long surface soil before it is accumulated by the new volcanic material. Before 600 years ago, the eruption of Ijen volcano was a magmatic eruption, while in the last 600 years, the eruption was phreatic. The stratigraphy on the slope of Ijen volcano consists of various pyroclastic deposits. The pyroclastic deposit is a type of fall, flow and phreatic. The oldest sedimentary group is a red pyroclastic deposit consisting of alternating pyroclastic fall with red pyroclastic flows. Red pyroclastic deposits were about 5,920 years, 20 years ago. This period is a period when Ijen volcano was still the beginning of the formation of the volcano body. The red pyroclastic deposit is lapile-sized with good gradation that has undergone the alteration. The deposit is overlaid by a gray pyroclastic fall deposit with no alignment. Among the red pyroclastic deposits with gray pyroclastic deposits, there is a long time span to form a soil layer and also undergo a process of erosion. The gray pyroclastic deposit was about 2,170 years, 160 years ago. The gray deposits lay a trace of charcoal from the branches of trees and grass. The gray pyroclastic deposit is classified in the first eruption sequence with the boundary that is the buried soil of the main material of the fall deposit with the andesite lapile fragments. The gray pyroclastic deposit above it deposited pyroclastic fall deposits of volcanic ash.

The deposit of volcanic ash was formed between $2,170, \pm 160$ years ago to 620 ± 120 years ago. The deposit fall of volcanic ash is brown-yellowish. The deposit of volcanic ash does not form a thick layer of soil above it. The youngest sediment is phreatic deposits. Phreatic deposits are younger than 620 years, 120 years ago. According to historical records begun in 1796, Ijen volcano only experienced a phreatic eruption. Based on these records, it is estimated that there is no other kind of volcanic deposits younger than phreatic deposits that settled on the slopes of Ijen Volcano until now [24].

3. METHOD

The instruments that were used are as follows: a set of resistivity meters, NRD 22S model, 4 pieces of electrode and cable as current and potential. The data obtained, taken with measurement coordinate points at a distance between 50 to 100 meters, or depending on the conditions of the field, can be seen in Table 1. This research made use of the sounding resistivity method with Schlumberger configuration. Figure 4 shows a resistivity measurement scheme done with this method. The instruments used to employ this method were a pair of current and potential electrodes that often shared the same center point but had different distances between adjacent electrodes [16]. The power supply flows the current into the ground through the current electrode. From the results read on the resistivity meter, it is obtained the potential difference values between the two electrodes. The depth obtained from the measurement using this method is $\frac{1}{2}$ of the total of span (AB). In principle, the farther the electrode span, the deeper the guessed depth of acquired [23].

Table 1. Coordinate of Measurement Point

Location	Coordinate		Altitude
	X	Y	
Ijen-1	858017	9107531	2349
Ijen-2	857970	9107652	2336
Ijen-3	858021	9107826	2369
Ijen-4	857910	9107365	2345
Ijen-5	857809	9107567	2268
Ijen-6	857697	9107668	2163

The parameters measured in the field were the distance between stations with electrodes (AB / 2 and MN / 2), current (I), and potential difference (V) [17]. The calculated parameters are a geometric factor (K) and resistivity (ρ). Eq.(1) is

the formula used to calculate the K and R values of data taken in the field.

$$K = \frac{\pi \left(\frac{AB}{2}\right)^2}{MN} \text{ and } \rho = \left(\frac{V}{I}\right) K \quad (1)$$

Whereas:

π = phi (3.14)

AB/2 = The Distance of station (center point) with electrode current (C) (meter)

MN/2 = The Distance of station (center point) with electrode potential (P) (meter)

K = Geometric factor

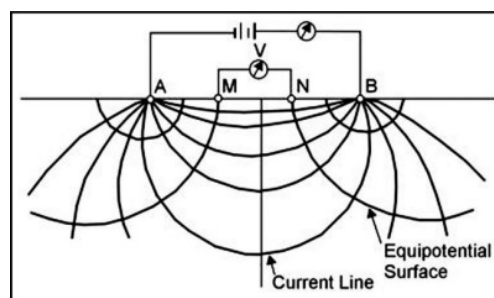


Fig. 4. Resistivity Method Schlumberger Configuration [25]

In terms of data processing and modeling, it is done by using IPI2win and progress 3.0. The data of the survey results are the potential difference value (V), the magnitude value of the current (I) being injected, the range of span AB/2, and the distance of MN is processed using IPI2win to obtain the geometrical factor (K) and resistivity value (ρ). To illustrate the lithology of rocks of geometry factor values and resistivity values using progress 3.0.

Interpretation based on the resistivity data is generally done by analyzing the properties of rocks, those are resistivity, porosity, the permeability of rocks, mineral content and others. The interpretation technique is done in two stages, the first stage is the curve obtained from field data processing compared to the mathematically calculated curve. Thus, it will be known the estimated value of the resistivity (ρ) and the thickness (h) of each layer. To obtain the smallest percentage of errors in interpretation, a mathematical inverse modeling approach using IPI2win software and progress 3.0 of field data and first-stage interpretation data were then performed.

From the resistivity value (ρ) and the thickness (h) of each rock layer as well as the contrast of the resistivity which is then correlated or compared with the geological data of the investigation area and other data, then it is obtained a description of subsurface lithology [22]. The value of resistivity of rocks, minerals, soils and chemical elements has generally been obtained through various measurements and can be used as a reference for

the process of conversion (table 2) [18] and the value is correlated with the geology of the research area.

Table 2. Resistivity Value of Rocks [18]

No	Material	Resistivity (Ωm)
1	Clay	1-100
2	Silt	10-200
3	Marls	3-70
4	Quartz	10-2x10 ⁸
5	Sandstone	50-500
6	Limestone	100-500
7	Lava	100-5x10 ⁴
8	Ground Water	0.5-300
9	Sea Water	0.2
10	Breccia	75-500
11	Andesit	100-200
12	Tuff	20-100

4. RESULTS AND DISCUSSION

At the point of Ijen-1, the maximum reachable depth was 90 m (Figure 5). There are several layers of stuff on the ground surface to a depth of 0.73 m. A thin lava insert is found at a depth of 0.73 m - 1.58 m. In the next layer, volcanic breccia is found at a depth 1.58 m - 18.04 m with a thickness of 16.64 m. The next layer is tuff, found at a depth of 18.04 - 30.44 m, underneath it there is a fairly thick layer of breccia found at a depth of 30.44 - 63.38 m with a thickness of 32.94 m. At the bottom layer, tuff is found at a depth of 63.38 m - 90 m.

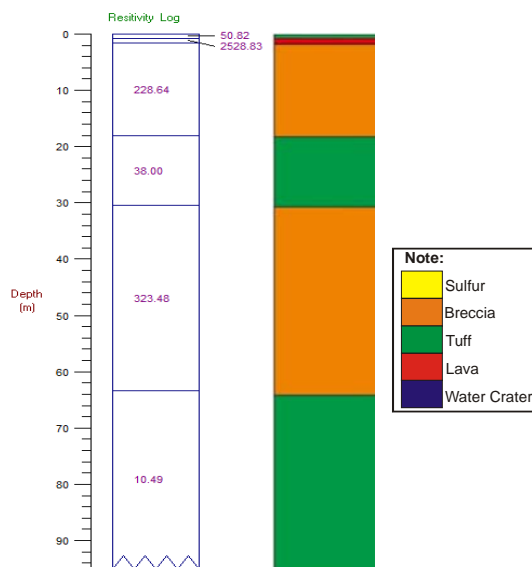


Fig. 5. Interpretation at the point of Ijen-1

At the point of Ijen-2, the maximum reachable depth is 60 m (Figure 6). There are several layers of stuff on the ground surface to a depth of 0.96 m. A thin lava insert is found at a depth of 0.96 m -

3.05 m. In the next layer, breccia is found at a depth of 6.99 m - 20.67 m. The bottom layer is a fairly thick layer of lava found at a depth of 20.67 - 60 m with a thickness of 39.33 m.

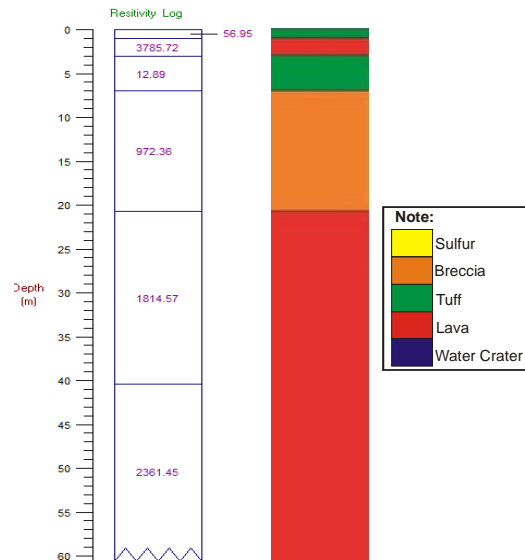


Fig. 6. Interpretation at the point of Ijen-2

At the point of Ijen-3, the maximum reachable depth is 110 m (Figure 7). There are several layers of breccia on the ground surface to a depth of 4.41 m. A lava insert is found at a depth of 4.42 m - 15.17 m. In the next layer, tuff is found at a depth of 15.17 - 17.9 m. The next layer of breccia is found at a depth of 17.19 - 28.73m. Underneath it, there is a fairly thick layer of lava found at a depth of 28.73 - 73.93 m with a thickness of 45.2 m. At the bottom layer, the tuff is found at a depth of 73.93 m - 110 m.

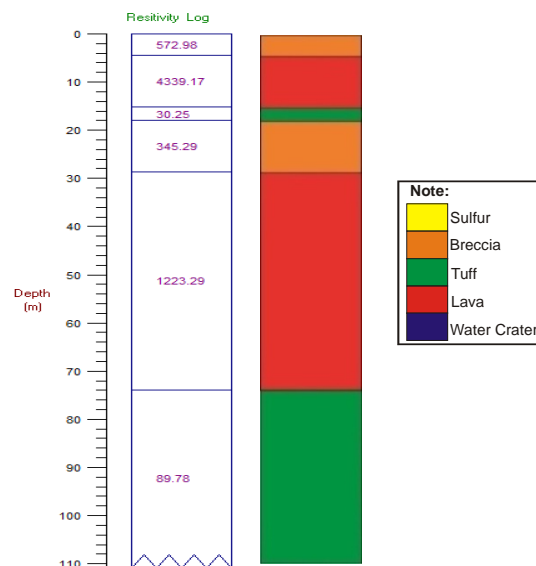


Fig. 7. Interpretation at the point of Ijen-3

At the point of Ijen-4, the maximum reachable depth is 100 m (Figure 8). There are several layers

of breccia on the ground surface to a depth of 0.59 m. A lava insert is found at a depth of 0.59 m - 2 m. In the next layer, tuff is found at a depth 2 - 4.73 m. The next layer is made of breccia, found at a depth of 4.73 - 18.77 m. Underneath it, there is sulfur found at a depth of 18.77 - 23.78 m with a thickness of 5.01 m. A fairly thick layer of breccia is found at a depth of 23.78 - 72.68 m with a thickness of 48.9 m. At the bottom layer, lava is also found at a depth of 72.68m - 100 m.

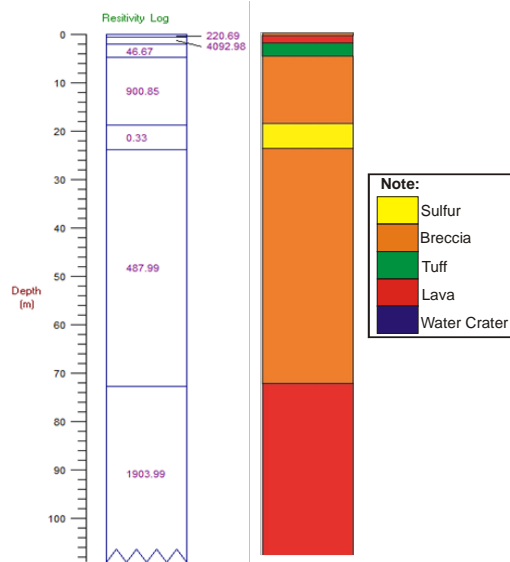


Fig. 8. Interpretation at the point of Ijen-4

At the point of Ijen-5, the maximum reachable depth is 45 m (Figure 9). There are several layers of breccia on the ground surface to a depth of 1.91 m. Tuff layer is found at a depth of 1.91 m - 24.95 m. There is sulfur found at a depth of 24.95 - 32.56 m with a thickness of 7.61 m, and the deepest layer of stuff found at a depth of 32.56 m - 45 m.

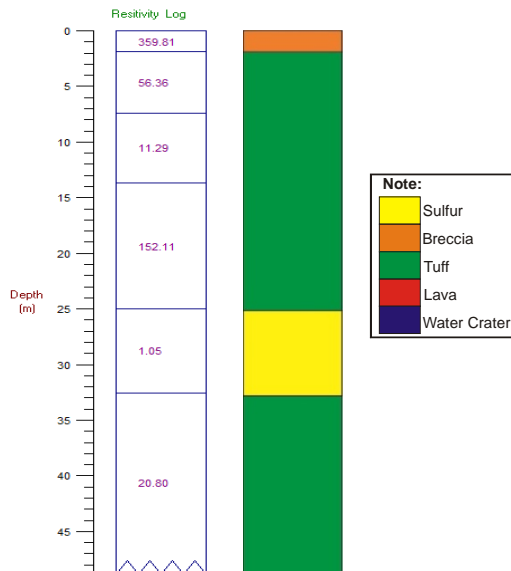


Fig. 9. Interpretation at the point of Ijen-5

Point-6 is located near the site of sulfur mining and of the crater water. In general, the value of rock resistivity obtained is quite small. At the surface, a layer of tuff is found at a depth of 0.69 m. In the following layer, at a depth of 0.69 m - 40 meter, a mix of sand and tuff is found with acidic crater water, which is a good conductor of electricity, so it makes the readable resistivity value quite small [20] (Figure 10).

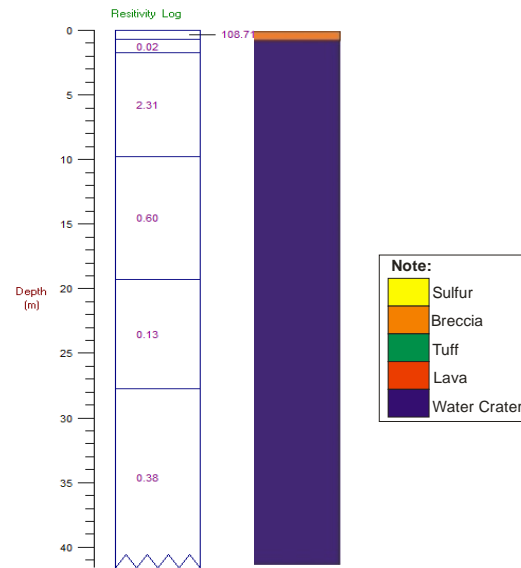


Fig. 10. Interpretation at the point of Ijen-6

Scattered point scan is modeled by interpolating several points into 2 and 3-dimensional models. It is useful to know the pattern, distribution, and direction of the existing lithology of the study area. Figure 11 is a 2D profile from point 1 to 4 obtained from the interpolation of the four points. Most of the lithologies are breccia and lava, tuff and sulfur. At point 3, there is a fairly thick layer of breccia above the lava, and also a little sulfur and breccia above this same layer. At point 2, the breccia layer is between the upper and lower tuff layers, which coincides with the lava at point 1. At point 1 and 4, lava dominates the lithology with a little layer of breccia at the top and it suppresses a fairly thick tuff layer under it.

Figure 12 is a 2D profile of points 2, 5, and 6. At point 1, lava dominates the lithology and there's volcanic breccia present at the top. The breccia infiltrates from point 2 to point 5; this is proved by finding breccia on the surface of point 5. A quite thick layer of tuff, breccia and a little bit of sulfur dominate the lithology at point 5. At point 6, which is located near the crater water, tuff is found at the top and it affects crater water at the bottom with its acidic properties, so the lithology at the bottom shows small resistivity value. The addition of the small breccia layer in Figure 12 shows the deformation caused by the slump or the structure of the eruption of Mount Ijen rock in the form of a

small crease slide down because of an appointment on consolidated layers that are perfect.

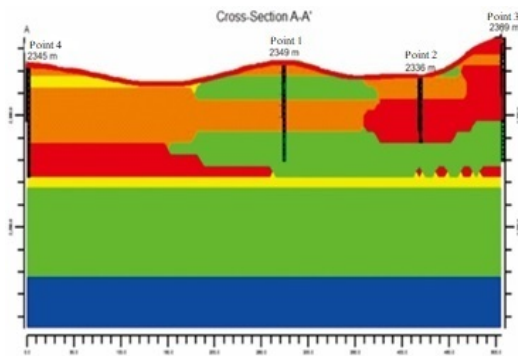


Fig. 11. 2D model from point 1 – 4

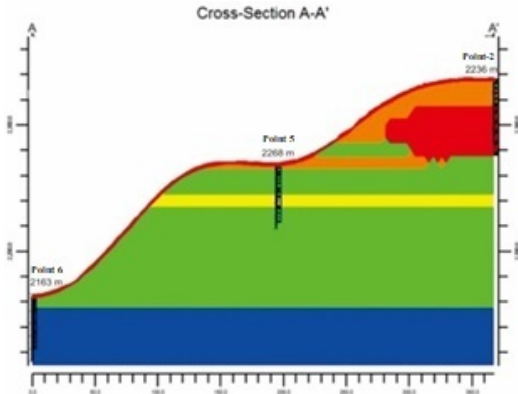


Fig. 11. 2D model from point 2.5 and 6

As can be seen in the diagram (Fig 13 and Fig. 14), breccia and lava dominate the lithology at point 4 and its distribution reaches point 1, which creeps between the tuff layer. A thin sulfur layer is also found between the breccia at point 4 leading to point 1, but it is cut off by a slope on the surface. While at point 3, lava dominates the lithology and it lies above the tuff layer. This lava layer spreads to point 2 and meets the breccia layer at point 2. Lava and breccia lie above the tuff layer that can be found at point 5. In addition, it is found that a thin sulfur layer infiltrates between the thick tuff layer that spreads to point 6, which is located near the crater. The material of crater water affects the lithology at point 6 with the properties of the electrolyte, so that it dominates the lithology at that location.

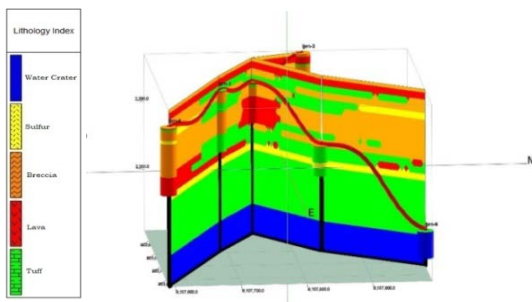


Fig. 13. Fence lithology visible from the East

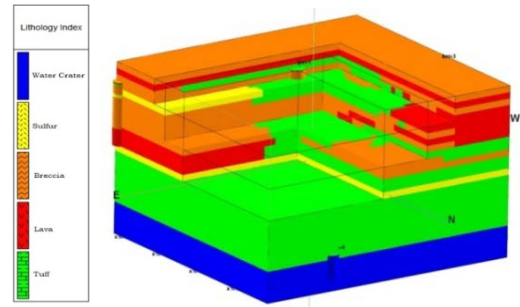


Fig. 14. Isosurface at the altitude of 164, 154, 144, 134, 124 and 144 meters

Using rockwork software, in figure 14 we can calculate the volume of each lithology (table 3). In the calculation of volume in the software rockwork using Delaunay triangulation method, where the depth data on existing lithology and stratigraphy modeling is entered into the datasheet, using the Borehole Manager's Stratigraphy Volume Tool associated with the data it will show the volume estimation from the rock [27].

Table 3. The volume of each lithology

Lithology	Volume (m ³)
Water Crater	9.020.000
Sulfur	2.621.000
Breccia	10.507.000
Lava	5.758.000
Tuff	20.802.000

5. CONCLUSION

The results of resistivity study at Ijen, can be summarized as follows: the lithology found at the crater of Mount Ijen is composed by tuff, volcanic breccia, lava, sulfur, and a mix of sand and tuff is found with acidic create water. The reservoir is characterized by a low resistivity value of tuff (10.49 Ω m – 89.78 Ω m). The reservoir is encountered at point 1 at a depth of 18.04 - 30.44 m with a thickness of 12.4 m and at a depth 63.38 m – 90 m with a thickness 26.62 m, at point 3 at a depth of 73.93 m - 110 m with a thickness of 36.07 m and at point 5 at a depth of 1.91 m - 24.95 m with thickness of 23.04 m and a depth of 32.56 m - 45 m with thickness of 12.44 m. The reservoir which is the main target of this study has a volume of 20.802.000 m³ which is about 42.7% of the total volume of the 3D model.

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