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Electrical Resistivity Survey of the Gunung Anyar Mud Volcano

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Abstract: The past oil and natural gas drilling activities have been presumed to cause a Mud Volcano phenomenon. The Mud Volcano potentially danger its surroundings, including the inhabitants. Thus, mapping the zone will be essential to have a mitigation plan. One of the potential Mud Volcanoes is the Gunung Anyar Mud Volcano. By using a resistivity survey, this research aims to obtain the subsurface structure of the Gunung Anyar Mud Volcano. The results show that very low resistivity values are located at the top of the soil structure with 0 to 4 meters depth. This soil structure is believed to be a manifestation of a mud volcano in the form of moistened clay associated with salt water. At subsequent depths, 4 to 5.5 meters from the top, is a layer of sandy clay. It is characterized by moderate to high resistivity values. At a depth of 5.5 to 10.5 meters, the resistivity value is very high. This sandstone layer is most likely a native subsoil formation in the Gunung Anyar area.

Keywords: electrical resistivity; wenner-schlumberger; mud volcano, gunung anyar

1. Introduction

Mud Volcano is a natural manifestation that indicates oil and gas potential in that area. Some researchers argue that the phenomenon of Mud Volcano is the result of a natural reaction to the past activities of the oil and natural gas drilling [1]. Apart from that, the phenomenon of Mud Volcano has the potential to be dangerous for the surrounding area. For example, Sidoarjo Mud Volcano (LUSI) has been spewing mud since May 2006 [2], [3]. The Sidoarjo mudflow has submerged four villages covering an area of 400 hectares and forced 45,000 people in the village to evacuate[4][5]. The Lapindo mud volcano has become Indonesia's most contentious and costly natural disaster. Despite its unusual geophysical characteristics, most people regard the mudflow as a social tragedy, as scientific disagreements over the disaster's causation have devolved into legal battles over culpability and justice[6]. Therefore, studying the Mud Volcano event is necessary as a disaster mitigation study as it affects people's life.

In Gunung Anyar districts, Surabaya city a Mud Volcano which is still actively releasing mud sediment despite a low discharge rate. Gunung Anyar Mud Volcano is located not far from residential areas. Mud Volano's zone mapping is the first step in disaster mitigation that can be done at this time. Mapping the sub-surface structure of Mud Volcano will improve the understanding of Mud Volcano. Geophysical survey methods are known as non-destructive methods. One of the geophysical survey methods is the resistivity method. Resistivity is an active method. The soil resistivity can be determined by sending an electric current into the ground. At the same time, the subsurface structure can be modeled without doing excavation from the resistivity data.

This study aimed to obtain the subsurface structure of the Gunung Anyar Mud Volcano area using a resistivity survey. Two resistivity survey lines leading west-east and north-south were carried out by using the Wenner-Schlumberger configuration. The results obtained from this study are expected to describe properly the presence of active mud location and the rock structure around old mud deposits that have hardened.

2. Literature Study

2.1 Gunung Anyar Mud Volcano

Mud Volcano is a cone-shape geological structure with a composition of mud, sediment, water, and gas on Earth [7], [8]. The formation of mud volcanoes occurs where underground rock formations are dominated by fine water-saturated sediments rapidly deposited under pressure from the rocks above. One driving force that pushes mud volcanoes is a gas explosion from within the Earth. The Mud Volcano phenomenon indicates the formation of oil reservoirs in that particular area [9].

Fig. 1. Gunung Anyar mud mountain

In East Java, there are five active mud volcanoes located in the Watukosek fault. A Mud Volcano can be disastrous if it is in a densely populated area. Uncontrolled mud release could drown inhabitants' homes around. One of the most famous is Sidoarjo Mud Volcano (LUSI), erupting in the Porong district, Sidoarjo City since May 2006. Another feasible example is Gunung Anyar Mud Volcano, located in the Gunung Anyar district of Surabaya City (7.34 longitudes, 112.78 latitudes). Gunung Anyar, which means New Mountain, is a hereditary name from former ancestors [10]. That Local wisdom shows that the Mud Volcano has existed in Gunung Anyar since ancient times. The fact also shows that the area was once an oil field during the Dutch East Indies era.

2.2 Resistivity survey

A resistivity survey is a non-destructive method for describing subsurface soil formations. Artificially generated electric currents generated by the resistivity meter are supplied to the ground, and the resulting potential differences are measured again by the resistivity meter [11]. The final result obtained is the apparent resistivity of the soil layer. The apparent resistivity values are then interpreted to predict the underground structure. Electric currents are assumed to flow in a homogenous and isotropic half-space. Therefore, the currents will flow in a hemispherical shape with radius r. The following formula applies:

$$V = \frac{\rho I}{2\pi r} \qquad (1)$$

The electrode is pierced into the ground for generating electric currents. In practice, there are usually four electrodes. The two current electrodes are A and B (also called C1 and C2). The two potential electrodes are M and N (or P1 and P2). Therefore, the potential difference V can be written as:

$$\Delta V = \frac{\rho I}{2\pi}\left[\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right] \tag{2}$$

Where, the geometric distance is expressed in AM, BM, AN, and BN. The apparent resistivity is expressed as:

$$\rho = \left[\frac{2\pi}{\left(\frac{1}{AM}\right)-\left(\frac{1}{BM}\right)-\left(\frac{1}{AN}\right)+\left(\frac{1}{BN}\right)}\right]\frac{\Delta V}{I} = K\frac{\Delta V}{I} \tag{3}$$

Where, K is called the geometric factor and depends on the electrode configuration selected.

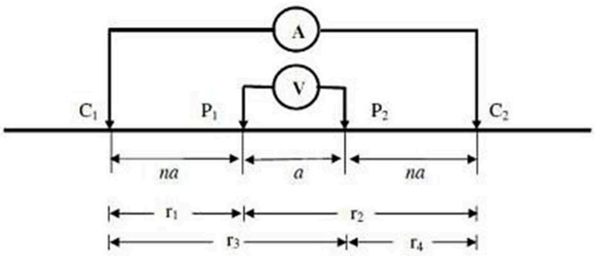

Fig. 2. Wenner-Schlumberger configuration

The Wenner-Schlumberger configuration combines the Wenner configuration and the Schlumberger configuration. When measuring the first spatial coefficient n=1, the Wenner-Schlumberger configuration is the same as the Wenner configuration (distance between electrodes=a). However, for measuring n=2, the Wenner-Schlumberger configuration follows the Schlumberger configuration rule (The distance between the current electrode and the potential electrode are larger than the distance between the potential electrodes). This configuration has the following geometry factor:

$$K = n(n+1)\pi a \tag{4}$$

With advances in electronics, computers, and software, resistivity studies have been developed to obtain 2D and 3D resistivity cross-sectional areas. This method is very powerful in identifying soil structure, soil type, and water content. Therefore, the geoelectric method is widely applied for various purposes such as groundwater exploration, understanding of soil thickness, and identification of bedrock. The results are then interpreted by using qualitative or quantitative way[12].

Resistivity methods have also been used to identify the underground structure of mud volcanic layers. According to a study by [13], [14], a resistivity tool (Pseudo3D ERT) combined with a digital elevation model (DEM) can characterize the underground structure of Piparomad Mountain in Trinidad and Tobago. The results showed a low resistivity value (<2.5 ohm.m) in the Mud Volcano sediment flows in the main vent. A high resistivity value (>3.2 ohm.m) is a lithofacial structure of sedimentary rocks due to mud deposits around the main hole. Another study was carried out in Mount Volcano Sidoarjo (LUSI) using resistivity methods (3D ERT) by [14]. As a result, the resistivity (3D ERT) shows cross-sectional areas in 0.14-141 ohm.m. The low resistivity indicates an active mud breccia with a high conductive hydrocarbon composition. The areas with high resistivity value are located around the cliff which is interpreted as mainly existing buildings buried with mud deposits. The Gunung Anyar Mud Volcano was investigated by [15] using a resistivity method. According to the author, resistivity anomaly indicates the distribution of mud towards the southeast. The results of this study will be compared to the findings of [15].

2.3 Soil Resistivity

Resistivity measures the resistance of a particular material to a particular size to electrical conduction. Resistivity is also known as electrical resistivity or volume resistivity, but these terms are less common. Materials resist the flow of electric current, but some materials conduct more current than other materials. Resistivity is an indicator that allows comparing how different materials allow or resist the flow of electricity. This resistance depends on the material compactness, the porosity and the permeability of the material, and the water content. To determine the type of formation by resistivity value, the resistivity table should be used as a guide, and the geological conditions of the area under investigation should be used. [16], [17]

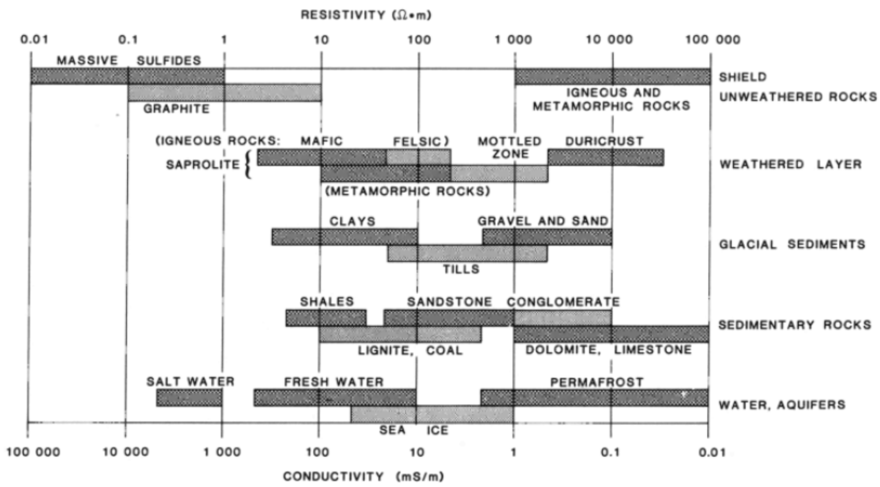

Fig. 3. Typical ranges of resistivities of earth materials [16]

3. Methodology

The research site is located in Gunung Anyar Mud Volcano, Surabaya City. The configuration of the resistivity survey is Wenner-Schlumberger. The MN potential electrode distance variation is 2, 4, and 6 m. The variation in the distance between the electrodes AB is 6, 10, 14, etcetera., until the distance of 30 m is reached. Line 1 runs west to east from point 1 (696742, 9188596) to point 2 (696753, 9188596). Line 2 runs north-south from point 3 (696762, 9188602) to point 4 (696761, 9188589).

Fig.4. Acquisition design of resistivity survey

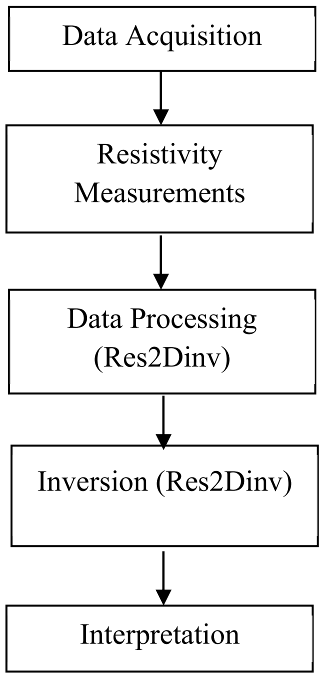

Fig.5. Research methodology

The first step in the processing chain is to obtain the resistivity value R by dividing the potential value V by the current value I. Then, the R-value was multiplied by the geometric coefficient value K to calculate the apparent resistivity value. The data then were inputted to Res2Dinv software for the inversion process using a least-squares method. The final result obtained is the cross-section of the soil resistivity layer. The results are analyzed and interpreted using the resistivity table of soil and the known geological structure from the area.

4. Test Result and Discussion

4.1. The result of data processing of line 1 (west to east)

The results produced by Res2Dinv software show the distribution of apparent resistivity value of the soil structure in color image format for both the vertical and horizontal sections (2D). Fig. 6 and Fig. 7 generated from the 14th and 7th iterations show the apparent resistivity distribution beneath the top of Gunung Anyar Mud Volcano hill at a 0 m to 10.5 m spread along 3 m to 15 m from west to east (696742, 9188596 to 69753, 9188596).

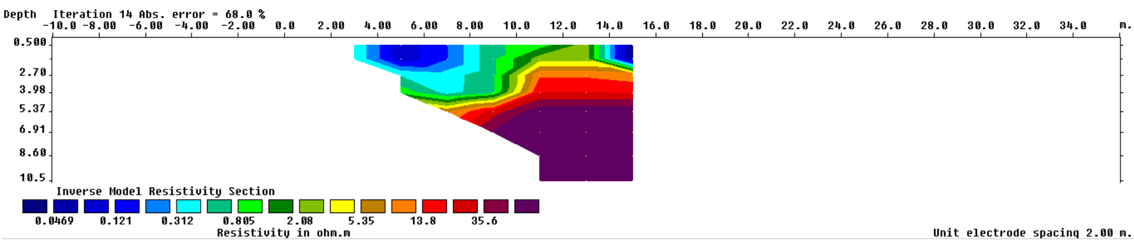

Fig. 6. Resistivity cross-section of line 1 (west to east)

From Fig. 6, it can be inferred that the minimum apparent resistivity value is 0.0005 ohm.m, and the maximum apparent resistivity value was 35.6 ohm.m. Then, it can be classified into specific soil types based on apparent resistivity tables and past research. At a distance of 3 to 8 m with depths of 0 m to 3.89 and distances of 14 to 15 m at a depth of up to 2.7 m, the apparent resistivity value is very low, shown in dark blue to light blue. It is interpreted as some air cavities filled with saltwater. Then, at adistance of 10 to 13 m with adepth of 2.7 m, the apparent resistivity value is low, shown in light green to yellow, and it is interpreted that the soil voids are partially filled with water. Then, the soil between 7 to 15 m at a depth of 3.98 to 10.5 m has a high apparent resistivity value, shown in red to purple color, and it is estimated that the soil is filled with air. Overall, the results are summarized in Table 1.

Table 1. Classification of apparent resistivity value of line 1 (west to east)

No	Color Gradation	Apparent Resistivity (Ω.m)	Soil Type
1		0,00 – 0,0469	Clay moistened with salted water
2		0,0469 – 0,0839	Clay moistened with salted water
3		0,0839 – 0,121	Clay moistened with salted water
4		0,121 – 0,2165	Clay moistened with salted water
5		0,2165 – 0,312	Clay moistened with salted water
6		0,312 – 0,5585	Clay moistened with salted water
7		0,5585 – 0,805	Clay moistened with salted water
8		0,805 – 1,4425	Clay moistened with salted water
9		1,4425 – 2,08	Sandy clay
10		2,08 – 3,715	Sandy clay
11		3,715 – 5,35	Sandy clay
12		5,35 – 9,575	Sandy clay
13		9,575 – 13,8	Sandy clay
14		13,8 – 24,7	Sandy clay
15		24,7 – 35,6	Sandy clay
16		35,6 – 46,5	Sandy clay
17		46,5 – 57,4	Sandy clay

4.2. The result of data processing of line 2 (north to south)

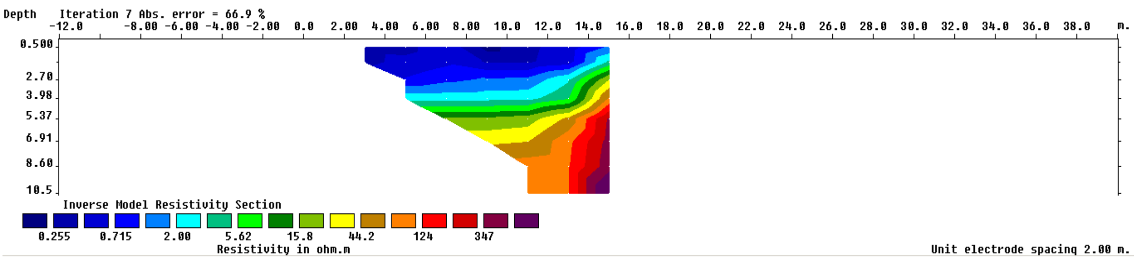

Fig.7. Resistivity cross-section of line 2 (north to south)

Fig. 7 is the resistivity cross-section of line 2 taken through the top of the mud volcano from north to south (696762, 9188602 to 696761, 9188589). From the Fig. 7, the minimum apparent resistivity value is 0.0005 ohm.m, and the maximum apparent resistivity value is 347 ohm.m. At 3 to 15 m and a depth of up to 2.7 m, apparent resistivity is very low, shown in dark blue to blue, and it is estimated that some voids are filled with saltwater. At a distance of 5 to 15 m with depth of 2.7 to 5.37m, the apparent resistivity is low, shown in light blue to light green. It is interpreted that the voids are filled with water. Then, between a distance of 8 to 15 m and a depth of 5.37 to 10.5 m, the apparent resistivity is high, shown in dark green to orange. It is predicted that soil is partially filled with air. However, at a distance of 13 to 15 m soil and a depth of 5.37 to 10.5 m, the apparent resistivity is very high, shown in red to purple, and it is estimated that the soil is filled with air. All the data interpretations are recapped in Table 2.

Table 2. Classification of apparent resistivity value of line 1 (west to east)

No	Color Gradation	Apparent Resistivity (Ω.m)	Soil Type
1		0,00 – 0,255	Clay moistened with salted water
2		0,255 – 0,485	Clay moistened with salted water
3		0,485 – 0,715	Clay moistened with salted water
4		0,715 – 1,357	Clay moistened with salted water
5		1,357 – 2,00	Sandy clay
6		2,00 – 3,81	Sandy clay
7		3,81 – 5,62	Sandy clay
8		5,62 – 10,71	Sandy clay
9		10,71 – 15,8	Sandy clay
10		15,8 – 30	Sandy clay
11		30 – 44,2	Sandy clay
12		44,2 – 84,1	Sandy clay
13		84,1 – 124	Sandy clay
14		124 – 235,5	Compacted sandstone
15		235,5 – 347	Compacted sandstone
16		347 – 458,5	Compacted sandstone
17		458,5 – 570	Compacted sandstone

5. Conclusion

The resistivity survey showed good results in describing the subsurface structure of the Gunung Anyar Mud Volcano. The two measurement lines share approximately the same results. Very low resistivity values are located at the top of the soil structure with a depth of 0 to 4 meters which are indicated by dark blue to light blue colors. This soil structure is believed to be a manifestation of a mud volcano in the form of moistened clay associated with saltwater. In other words, this layer is an actively wet mud layer that extruded from within the earth with a very slow discharge rate. This result is in line with research by (Kurnia S & Jaya Santosa, 2016) which shows that the mud layer has a fairly low average of apparent resistivity value, ±0.5 ohm.m. At subsequent depths, 4 to 5.5 meters from the top, is a layer of sandy clay (partially filled with air). It is characterized by moderate to high resistivity values. So that it can be interpreted as a hardened mud associated with the surrounding sandstone. Finally, at a depth of 5.5 to 10.5 meters, the resistivity value is very high. Subsoil structure is interpreted as a hollow sandstone that has hardened. This sandstone layer is most likely a native subsoil formation in the Gunung Anyar area. In the future, it is necessary to conduct a more in-depth study to understand the formation of the Gunung Anyar Mud Volcano. For example, with the addition of a resistivity acquisition design, the subsurface conditions of Mud Volcano can be better described. Integration with other geophysical methods can be carried out so that resulted a more comprehensive understanding of the Gunung Anyar Mud Volcano.

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