# Geophysical Approach And Geochemistry Correlated To Discover Underground Water Flow Indicator To Mud Volcano In Quarter Volcanic System

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***ABSTRACT***

*No less than 108 million meter3 of hot mud has been spread out from the earth since the burst first occurred in Porong, Sidoarjo at May 29th, 2006 until this day. This mud has covered the area for more than 717.027 ha with inundation that reaches many meters deep. If a close attention is being paid, 70% contain of the mud is water. Because of that, water volumes which have been produced is no less than 75 million m3. Therefore, information of subsurface geological data of the region around the burst site is needed to find out where the source of water came from. This study is meant to get a subsurface image of Porong so that a subsurface water channel that supplies water to the centre of mud burst can be found. Geophysical data, which is in the form of gravity method, Audio Magnetotelluric (AMT), and Magnetotelluric are correlated with geochemical study of elements of the mud. Pb, Zn, Mn, Ag, Cd, Sb, Au, Se, and Hg elements which the hot mud have is indication of hydrothermal influence at 100°C that come from the quarter volcanic system around the mud source such as Pananggungan Mountain and Arjuna Mountain. Not only that, result of measurement, gravity interpretation in form of Bouger anomaly, AMT, and MT data show three lineament structures in NE – SW direction in Porong, Sidoarjo. One of them extends from Watukosek Village in Pananggungan Mountain to the mud lake of Sidoarjo. This lineament is interpreted as a fault zone with 0.2 – 0.7 km deep in Watukosek Village and even gets deeper in the mud lake area (1.5 – 3 km deep). The Fault is a permeable zone which acts as the subsurface water channel. This channel is interpreted as the way of water flow, so the mud burst still continuous until this day.*

**Keywords**: geophysics, geochemistry, subsurface structure, subsurface water flow, Sidoarjo

## INTRODUCTION

Location of Lapindo lying on Siring village, subdistrict Porong, distrik sidoarjo (lampiran1). Mud Volcano in Sidoarjo have interesting geological phenomenon and attract not just local geologist also expertise from abroad. First burst happened at Sumur Banjar Panji 1 (BJP1) Surrounding. With 5000m$^3$/day discharge. Bursts hole happened on several places, before become one giant hole, mud volcano bursts increased on may-augusts 2006 reach 126.000 m$^3$/day (Suprapto et al, 2007)

Mud volcano phenomenon triggering many expert to make a lot of hypothesis about occurrence mechanisms, including non geological petroleoum attended mechanism occurrence mud volcano. Temperature mud in the beginning just considered as geothermal gradien factor. But when increased to almost 100$^O$C. It gives anoter alternatif hypothesis beyond gradien geothermal aspect (Suprapto et al, 2007). Although it happened in sediment basin, but its possible that magmatic influence accompanying emergence mechanism mud volcano. This is supported by the presence of Quaternary volcanic rocks, which are located about two kilometers south of the center of the eruption, and there is also volcanic activity.

Based on the description above, the purpose of this study is to analyze the correlation of subsidence patterns that occur in the main eruption area based on remote sensing data with the geochemistry data of the mudflow, so that the delineation of the subsidence occurrence pattern can be carried out with the surrounding Quaternary volcanic system (focus on the Mount Penanggungan volcanic system. and Mount Arjuno) (Figure 1).

## GEOLOGY OF THE STUDY AREA

The main burst is located at the end of a flat valley about 20 km from the coast with an altitude of about 3 m above sea level (asl). The valley has a height of 1 - 2 m above sea level, flanked by the Balongati River and the Porong River which extends eastward to the sea with a very gentle slope (0.015%).
The end of the valley turns slightly to the northeast because it is obstructed by the delta formed by the Porong River, the area around the subsidence is the alluvium plain which is a delta known as Delta Brantas, which Kadar et al. (2007), is described as follows: alternating between sand and shale ± 848 m (2,782.2 ft) thick which is correlated with the Pucangan Formation. In the center is a bluish-gray clay of the Upper Kalibeng Formation with a thickness of 1,285 m (4,215.9 ft). Under the Kalibeng Formation, medium to coarse grained dark gray volcanic sand is found, with



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a thickness of more than 944 m (> 3,097.1 ft) (Sudarsono et al., 2007)

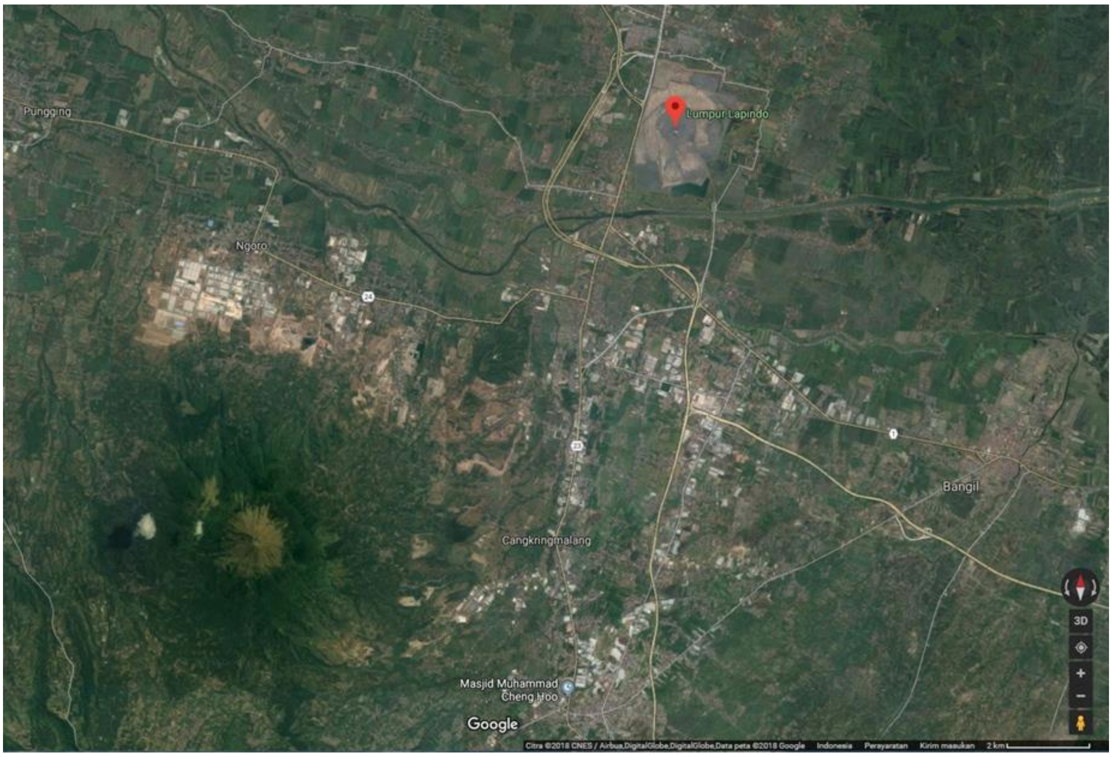


Figure 1 The location of the Siduarjo mudflow which is adjacent to the volcanic quaternary of the Penanggunagan volcano.

According to Suprapto et al (2007), physiographically the activity area is included in the Randublatung Zone which is a narrow zone extending about 250 km and a width of 10 km from Semarang to Surabaya. The subsurface structure of the Randublatung Zone is indicated as a triangle zone, a triangular zone flanked by fault zones with opposite slopes and directions. In Central Java and East Java, the Randublatung Zone is the area where two large zones meet, namely the Rembang Zone and the Kendeng Zone. The Rembang Zone is an area of exposure and a slope characterized by a predominance of upward faults leading (vergency) to the south. Kendeng Zone is a slope and bathyal with the dominance of upward faults to the north. In the meeting area, a very narrow, elongated and very deep zone is formed which is called the Randublatung Zone.

In the Oligo-Miocene this zone is isostatically submerged to compensate for the uplift in both clamp zones and is a good kitchen for the accumulation of hydrocarbons as long as there is a supply of organic-rich sediment deposited in it. The subsided triangle zone has implications for the maturation of the source rock and the presence of a subthrust structure under the upward fault zone to be a good trap, while the reservoir will depend on the presence of reservoir-quality sediments from a shallower environment. The quartz sandstones of the Kerek and Merawu Formations, which are Middle Miocene, and sediments of quartzan debris from the Ngrayong Formation, which are Middle Miocene, are deposited into the Randublatung and Kendeng Zones, the source of which contains many marl flakes and other calcareous sediments (Suprapto et al., 2007).

**RESEARCH METHOD**

The method in this study includes two major aspects, namely the framework and data collection methods. In the framework of thinking, theoretical concepts will be used to achieve the research objectives, while the data collection methods are obtained from previous researchers.

Remote sensing data used in this study comes from the results of monitoring using GPS (Global Positioning System) and interferograms from the Center for Geological Environment (2007). Interferogram analysis was performed based on PALSAR (Phased Array type L-band Synthetic Aperture Radar) data with ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer)



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background L3A. PLG (2007) conducted observations for 46 days (4 October 2006 to 19 November 2006). The results of the interferogram analysis are then depicted in a topographic map.

Sidoarjo mud geochemical data used in this study is sourced from the Center for Geological Resources (2007). Mud samples were taken between 28 March 2007 and 11 May 2007. Mud samples were collected at a location around the embankment. The fluid taken has a temperature of 100 C which has the potential to dissolve Cu, Pb, Zn, Mn, Ag, Fe, Cd, As, Sb, Au, and Se metal elements. One sample was taken at each location.

AMT (Audio Magneto telluric) and MT (Magneto telluric) data were obtained from research by Karit L. Gaol (2016). In collecting data obtained in this study are in the form of field surveys, laboratory and studio analysis. The field survey is in the form of geophysical measurements using the AMT and MT methods. In studio analysis, the AMT / MT 2-D resistivity model is obtained. subsurface mapping study is intended to obtain subsurface structure conditions in the research area.

The hypothesis put forward is that there is a correlation between the subsidence pattern of remote sensing data on the geochemistry of Sidoarjo Mud which is influenced by the hydrothermal system of Mount Penanggungan and Mount Arjuno and this pattern is indicated because of the influence of the fault structure developing in the study area.

## RESULT AND DISCUSSION

### Remote Sensing Data Analysis

Based on the analysis of GPS data, it is seen that the occurrence of large vertical and horizontal movements and their directions varies. But in general, horizontal movements focus on the center of the blast. Based on the movement, the observation for 122 days, near the main burst is 76.2 cm for horizontal movement for vertical movement. If the average is taken, the horizontal movement is 0.6 cm / day and the vertical movement is about 1.85 cm / day (Figure 2).

The results of interferogram analysis using PALSAR data show that around the main burst there are symptoms of subsidence. The observations show that there has been a subsidence of 90cm or about 1.96 cm / day and is in the form of an ellipse with an area of 5.2 km2. The results of the interferogran analysis are then depicted in the form of a topographic map as shown in (Figure 3).

By combining the observation data with GPS and the results of interferogram analysis, as well as the damage that occurs in areas prone to subsidence, covering an area of 6.3 km2 covering Tanggulangin District: Kedungbendo Village, Porong District: Siring Village, Jatirejo Village, Mindi Village, and Renokenongo Village, as well as Jabon District: Pejarakan Village and Besuki Village.

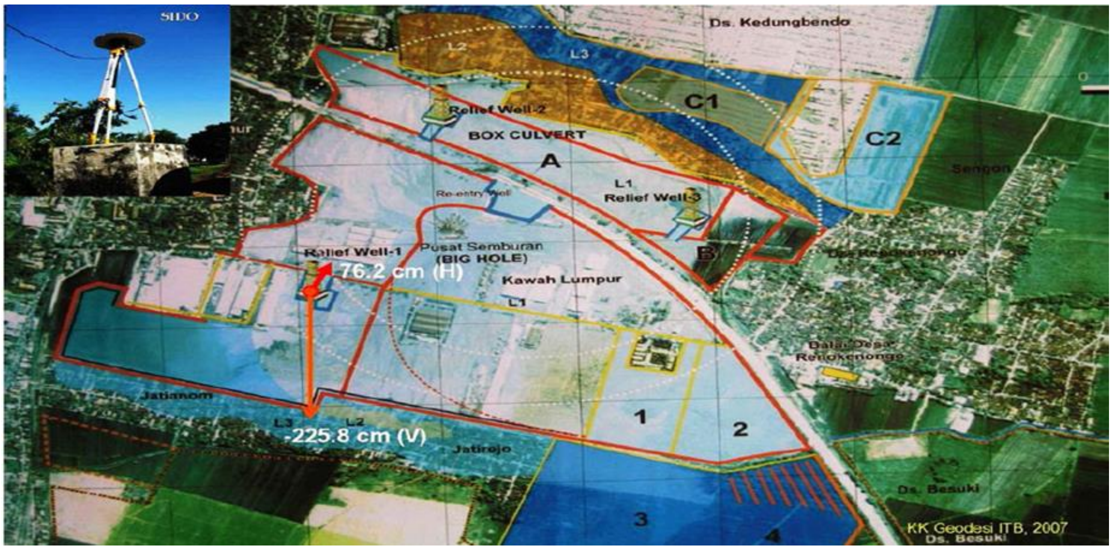


Figure 2 Results of monitoring with GPS (Abidin et al., 2007.)

### Geochemical Data Analysis

According to the Center for Geological Resources, geothermal fluids are acidic, they have the potential to dissolve metal elements, so that the elemental content in the mud will be affected. Temperatures with a range close to 100oC are epithermal zones which are generally the zone where Cu, Pb, Zn, Mn, Fe, Cd, As, Sb, Au, Ag, Hg, and Se are found (Table 1).



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Geothermal fluid comes from magma residual fluid, it can also be groundwater which is conduced by magmatic heat, or a mixture of the two. Geothermal fluid characteristics are not always constant, it can change depending on the magmatic activity itself and the geohydrological cycle in the surrounding zone. The pH measurement results in the field show that the sludge is alkaline with a pH value range of 8-9. The results of chemical analysis showed that the comparison between the range of metal content in the sludge and the average content of metal elements in claystone in the earth's crust was slightly higher for some elements.

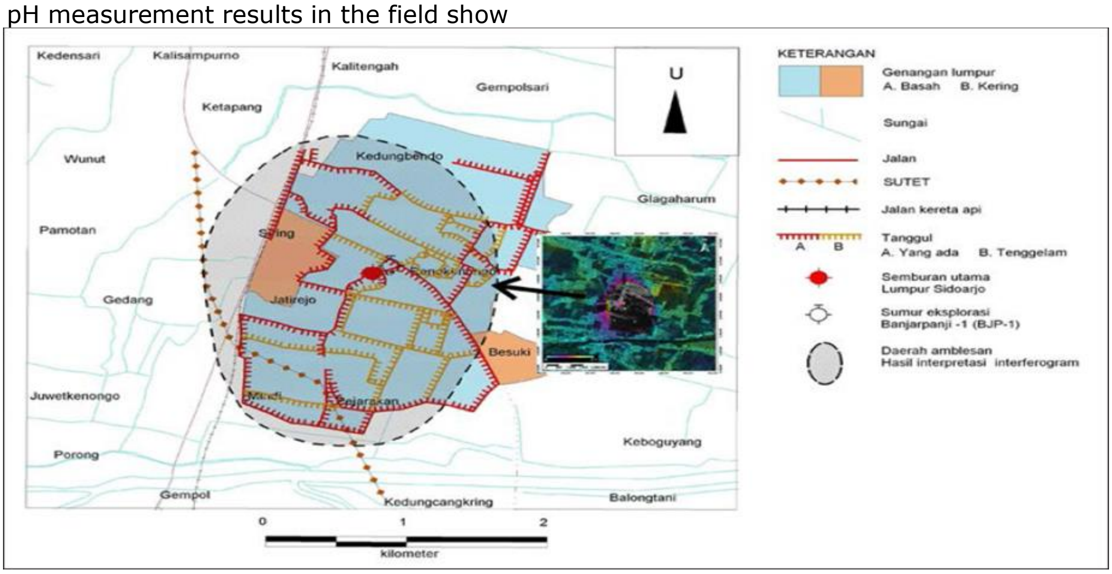


Figure 3 The results of the interferogram analysis (Deguchi et al., 2007.)

The As content is below the average but the distribution pattern of the elements shows a higher value towards the center of the burst, the Au distribution at the center of the burst has a lower value but towards the North shows an increase, the distribution of Cd and Cu elements has a relatively high average. High values were also found around the center of the burst. Although the distribution pattern of Cd and Cu elements tends to be less regular, the higher the blast center approaches, the average Fe content is relatively low. The distribution pattern is similar to Cu and Cd. The content of Fe even though there is a recharge from the mudflow, however, shows a significant increase. The Hg element has a relatively high average price and has an increasing pattern in the area around the center of the burst. Kisara Mn values are 317-1095 ppm, the average is relatively low, but there are high values in some locations, high values are near the center of the burst and at locations far from the center of the burst. The average price of Pb has a distribution pattern with high values found far from the center of the burst, especially in the north, decreasing in the south. The content value of 7-30 ppm in the Sb content is relatively high and is located at the center of the burst and its surroundings. Se content has a rather high average, especially in areas far from the center of the burst, and begins to decrease

Table 1 Summary statistics of the metal content of 86 mud samples and comparison levels in claystone (Units in ppm except Fe:%, Au & Hg: ppb) (Suprapto, J.S)

| Elements | Min | Max | Average | Standard Deviation | Average in claystone |
|---|---|---|---|---|---|
| **Cu** | 19 | 47 | 22,49 | 4,508 | 42 |
| **Pb** | 37 | 72 | 49,40 | 5,693 | 25 |
| **Zn** | 77 | 142 | 96,29 | 11,483 | 100 |
| **Mn** | 317 | 1095 | 653,78 | 101,992 | 850 |
| **Ag** | 0 | 2 | 0,95 | 0,270 | 0,19 |
| **Fe** | 3,12 | 3,98 | 3,55 | 0,38 | 4,7 |
| **Cd** | 4 | 8 | 6,01 | 0,888 | 0,3 |
| **As** | 1 | 10 | 3,46 | 1,934 | 12 |
| **Sb** | 1 | 30 | 4,13 | 4,774 | 1-2 |
| **Au** | 1 | 15 | 5,37 | 4,092 | 4 |
| **Se** | 2,6 | 127 | 83,528 | 24,380 | 0,6 |



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| | | | | | |
|---|---|---|---|---|---|
| **Hg** | 0 | 106 | 20,41 | 18,245 | 0,02-0,4 |

further south from the center of the burst, and the average Zn content is below the average, but has a rather high value range of 100-142 ppm is near the center of the continuous burst to the south.

**Magnetotelluric data**

Measurement of magnetotelluric (MT) data stretches southwest-northeast from Watukosek Village in the bearing area to the Porong area, which results in 9 measuring points made in the form of a magnetotelluric resistivity (MT) cross section, with intervals between measuring points of approximately 1 km (Figure 4).

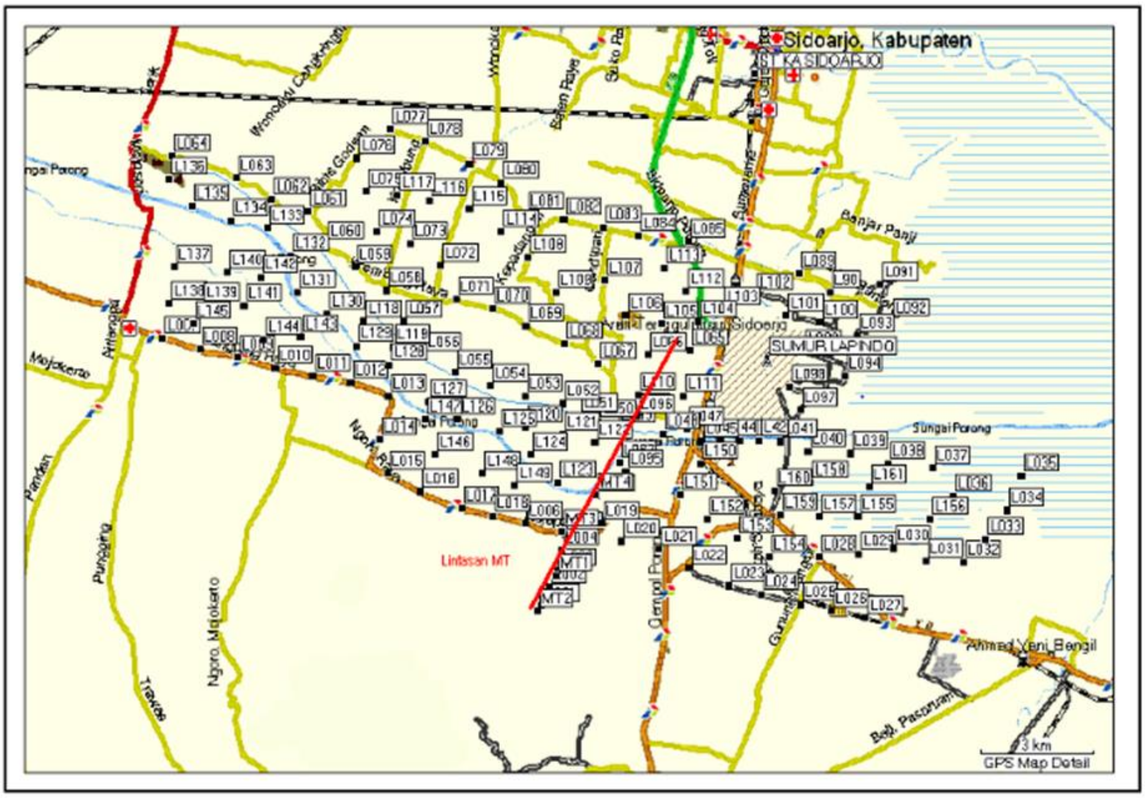


Figure 4 The location of Magnetotelluric data collection stretches southwest-northeast from Watukosek Village in a rigid area up to the Porong area, (Karit L. Goal, 2016)

Based on the cross-section of the 2d magnetotelluric resistivity (MT) model (Figure 5), it produces several layers of resistivity groups. namely the first one that is characterized by blue in the 1080 0hm-m group of prisoners, the second in white is included in the 80-200 Ohm-m group of prisoners, and the third is pink in the 200-500 Ohm-m group of prisoners and the fourth is dark red including resistivity 5000-10000 Ohm-m. The first layer occupies an area starting from the MT-4 to MT-9 measuring points. At the MT-3 measuring point this layer appears starting from the surface with a thickness of 0-500 m to the MT-5 point. From the MT-5 point, this layer was slightly thinner again with a thickness range of 0-100m at the MT-7 point then thickened slightly again, starting from 0-400m at the MT-8 point. From the point MT-8 towards MT-9 is again experiencing depletion with a thickness ranging from 0-200m. the second layer is spread from the MT-2 measuring point to the MT-9 measuring point. In general, the thickness of this layer is almost homogeneous under the first layer and shows a continuous pattern up to the MT-9 measuring point. The thickness of this second layer is estimated to be 200m on average. the third layer is distributed from the MT-1 to MT-9 measuring points. At the MT-1 and 2 measuring points this layer appears to appear near the surface, then continuously under the first and second layers until the MT-9 measuring point. Between the points of MT-2 and MT-3, in this layer there is a zone of weakened resistivity that continues to weaken from a depth of 250m to a depth of more than 1500m. Then starting from point MT-4 to point MT-9 it is estimated that the average thickness of this rock layer is 300m with varying thicknesses ranging from 600m at MT-4 to 1200m at MT-



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5 and at MT-7 point it returns shallower until 400m depth from the surface. This pattern has the same repetition until the point MT-9 follows the pattern of the layer above it. The fourth layer is found at the MT-1 point starting from a depth of 400m from the surface to a depth of more than 1500m. Then, at the MT-4 point this layer starts from a depth of 1000m from the surface to a continuous rise to a depth of 600m at the MT-7 point and continues to repeat itself following the layer above it to the point MT-9.

This weakening resistivity pattern indicates that the Zone has reduced rock cohesiveness and this can be caused by movement or deformation that occurs due to fracture structures. This fault appears to be the southern tip of the fault structure identified in the deconvolution method, at the foot of Mount Penanggungan.

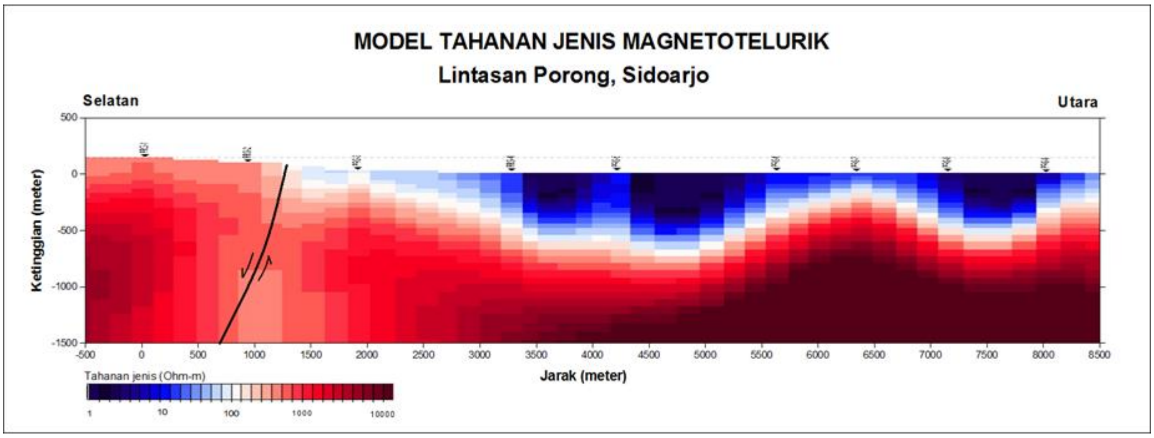


Figure 5 Rock distribution based on resistivity and structural interpretation based on the 2-D cross-section of the MT resistivity model in the Porong area, Siduarjo (Karit L. Goal, 2016).

## CONCLUSION

Based on the results and discussion above, there is a pattern of subsidence in the form of an ellipse with NE-SW direction in the center of the eruption that leads to the Penanggungan mountain and the correlation between the main source of mud and the hydrothermal system of the nearest volcano, it is evident that there is a similarity of chemical elements in Sidoarjo mud with The hydrothermal system in Mount Pananggungan is supported by fault patterns from Magnetologic data showing a shallower depth of fault structure between 0.2 to 0.7km, but it is likely that this structure continues to a deeper depth, as seen in the 2-D MT resistance section. This result means that the water supply channel from the Watukosek area to the mud lake location can take place from a depth of 200m to 1500m, where this is a permeable zone that can act as a subsurface water channel. This channel is interpreted as a water supply road to the center of the eruption so that the mudflow continues to this day.

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