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THE SUBSURFACE STRUCTURE ANALYSIS OF GAMBAR WETAN TEMPLE, BLITAR USING VERY LOW FREQUENCY ELECTROMAGNETIC (VLF-EM) METHOD

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Abstract

A geophysical investigation to study anomalies and determine the distribution of rocks within the subsurface using the Very Low Frequency Electromagnetic (VLF-EM) method was conducted around Gambar Wetan Temple. We have measured subsurface structure by dividing the area into several tracks. The spacing of trajectory is 1 meter. The measurement was done at each point on each trajectory with spacing of 0.5 meters. As a result, we get the data of inphase, quadrature, t-fields, and tilt. Noise-Assisted Multivariate Empirical Mode Decomposition (NA-MEMD) was applied to the data to denoise the signal of VLF-EM data. The NA-MEMD filtered data were then interpreted qualitatively using Karous-Hjelt filter to get the location of the anomaly which is more conductive or more resistive. Quantitative interpretation using Inv2DVLF-v1 for the inversion of tipper data (inphase and quadrature) were also done to get the apparent resistivity profile. Then, both were combined to get the overall interpretation. The results showed that there are generally two anomalies detected around the temple in 4 lines measurement, conductive and resistive anomaly. The resistive anomalies which are predicted as andesit has a resistivity 120-220 Ωm at depth of 0-40 meters. This is expected to help in finding rocks within the subsurface because the main temple has not been found.

Keywords: VLF-EM, rock, NA-MEMD, Karous Hjelt, inversion.

INTRODUCTION

Gambar Wetan Temple, one of the historical heritage, is located in the district of Blitar, East Java, Indonesia. This temple is located close to Mount Kelud, an active volcano that eruption issued a lot of volcanic material and it can hoard the surrounding. The first discovery of Gambar Wetan Temple was a statue. Then, a place of worship and other statues were found in the following years. The latest discovery on May 2014 was a statue. Allegedly, there are many parts of the temple that still buried in the subsurface. Therefore, it is necessary to further study in the area around Gambar Wetan Temple to identify the structure of subsurface.

This study tries to investigate anomalies and determine the distribution of rocks within subsurface through the resistivity. Soil resistivity is associated with various geological parameters such as mineral and fluid content, porosity, degree of fracture, the percentage of soil water-filled fracture, and the degree of water saturation in the rock (Singh, 2004).

Very Low Frequency Electromagnetic Method (VLF-EM) can be used to identify the different resistivity in igneous rocks and in sediment quickly (Abbas et al., 2012). It is helpful in efforts to seek out information about the subsurface geological condition in order to predict the composition of the rocks that are still buried in the ground. The advantages of using this method are easy to use because the weight is light, fast data recording, and environmentally friendly. VLF electromagnetic method is passive method that works at a frequency of 15-25 KHz (McNeill and Labson, 1993). This is a sufficient low frequency that causes the wave has a deep enough penetration. These waves spread throughout the world with little attenuation in the waveguide between the earth's surface and the ionosphere. The data were recorded including inphase, quadrature, tilt, and t-fields.

The wave propagation in Very Low Frequency (VLF) is only in transverse electric (TE) mode (Kalscheuer et al, 2008) because output on VLF recording is data tipper (Hz / Hy) which is complex due to polarization between Hz and Hy. If the value of Hz and Hy is not equal so the polarization is ellips. If the value of them is equal so the polarization is circular. The real part of data tipper is inphase, while the imaginary part is quadrature. Tipper data is suitable for mapping the conductivity difference laterally and less good for vertical conductivity differences. If under the surface there is a conductive medium, the magnetic field component of the primary electromagnetic wave will induce the medium causing the induced current (Eddy Current).

Eddy current generates new electromagnetic field called secondary electromagnetic field, Hs, which has a horizontal component and vertical component. The magnetic field has a section in phase and different phases (quadrature) with primary field. The secondary electromagnetic field depends on the object's conductivity within the subsurface.

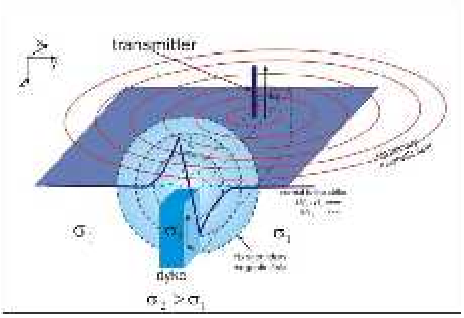

Figure 1. Eddy Current generates new electromagnetic field called secondary electromagnetic field (Bosch and Muller, 2001).

The depth of wave penetration in the VLF-EM is often regarded as the skin depth (δ) which is defined as:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}} \approx 504\sqrt{\frac{\rho}{f}}$$

ρ denotes the resistivity of subsurface and f is the frequency of the transmitter.

RESEARCH METHOD

Data acquisition was done around Gambar Wetan Temple by dividing the area into several tracks. Each track has a long stretch of measurement ± 100 meters. Trajectories were made parallel. The spacing of each trajectory was 1 meter. The measurement was done at each point on each trajectory with spacing of 0.5 meters (Figure 2). The spacing is based on the statues, including sedimentary rocks that have been found, have a small size with 0.5 to 1 meter long. So we estimate the sedimentary rocks that are still hidden within subsurface can be smaller than 0.5 meters in length. Data recording was taken by using conventional techniques (standing) with operator was directed to the transmitter. At each point of measurement, the tool of VLF-EM was operated and all recorded data by Envi Scintrex was noted. The result of measurement was the value of inphase, quadrature, t-field, and tilt.

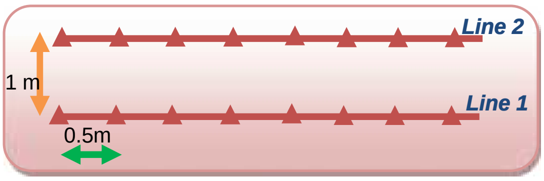

Figure 2. The spacing of each trajectory and each point of measurement

The result of measurement was rewritten on Microsoft Excel. Then, data of inphase and quadrature was inserted into matlab to be filtered by NA-MEMD, software for reducing noise of high frequency signal. After that, the NA-MEMD filtered data was interpreted qualitatively and quantitatively. Qualitative interpretation was done by using the Karous-Hjelt Filter to get the location of anomaly which is more conductive or more resistive. Bayrak (2002) explained that using Fraser Filter (1969) and Karous-Hjelt Filter (1983) on VLF method can be used to localize the location of material which is more conductive in the observation area. Karous-Hjelt Filter is a refinement of Fraser Filter. Quantitative interpretation was done by using Inv2DVLF-v1 to get the apparent resistivity profile. Santos et.al, (2006) introduced a quantitative analysis of the VLF data by using the inverse of tipper (inphase and quadrature). The result was a 2-D resistivity values that could image the subsurface structure well. However, this quantitative analysis requires qualitative analysis information for the initial input design (Bahri et al, 2008). The last of this step was overall interpretation by integrating an analysis of them, qualitative and quantitative.

RESULT AND DISCUSSION

Based on NA-MEMD filtered data, the amplitude of quadrature is much smaller than the amplitude of inphase. It causes the inphase is more sensitive than quadrature in detecting anomalies. So, the quantitative interpretation in Karous-Hjelt Filter was done for inphase only. The inversion of each trajectory was done 100 times of iteration and the initial resistivity was 120 Ωm. The Lagrange's parameter, an inversion constraint, was 0.7. The environment frequency, which was recorded by VLF-EM was 19.8 KHz. By using equation 1, the depth of penetration was 40 meters. These are the results of Karous-Hjelt Filter and inversion:

- **Line 1**

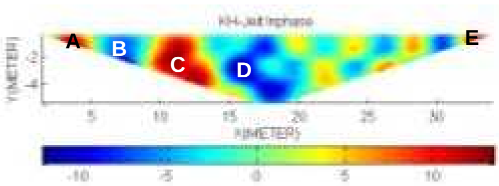

Figure 3. The Result of Karous-Hjelt Filter Line 1

The result of Karous-Hjelt Filter is shown in Figure 3. There are three resistive anomalies (A,C,E) and two conductive anomalies (B,D). Resistive anomaly has positive current density, while conductive anomaly has negative current density. The result of inversion is shown in Figure 4. The root mean square (rms) or error data is 1.49. The anomalies at depth 0-5 meters have the same profile with anomalies in Figure 3. At depth 5-

40 meters, the subsurface is dominated by material with resistivity 140-200 Ωm. Telford (1990) explained that the rock which has resistivity 100-200 Ωm is andesite. Based on this information, it can be estimated that the material which dominate the subsurface is andesite.

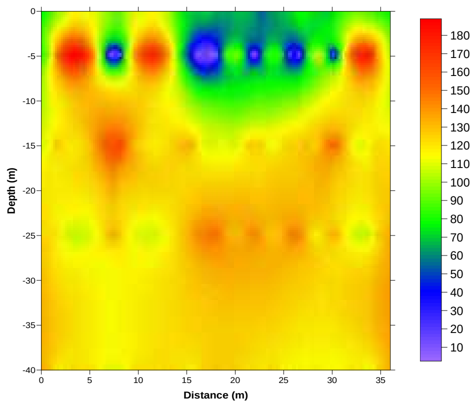

Figure 4. The Result of Inversion Line 1

- **Line 2**

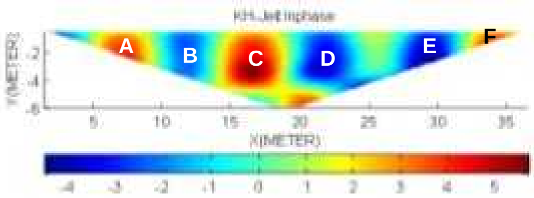

Figure 5. The Result of Karous-Hjelt Filter Line 2

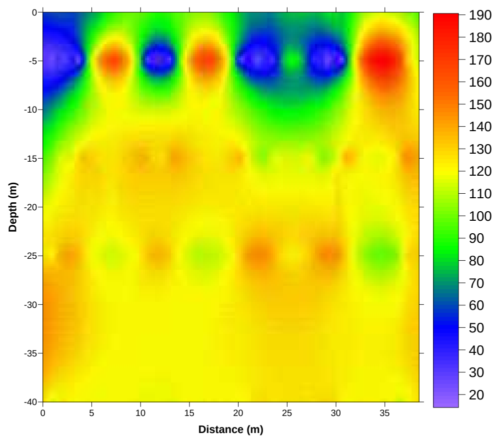

Figure 6. The Result of Inversion Line 2

In Figure 5, there are three resistive anomalies (A,C,F) and three conductive anomalies (B,D,E). In Figure 6, there are anomalies that same as Figure 5 at depth 0-5 meters. While, at depth 5-40 meters is dominated by materials with resistivity 130-170 Ωm. The rms is 0.56.

- **Line 3**

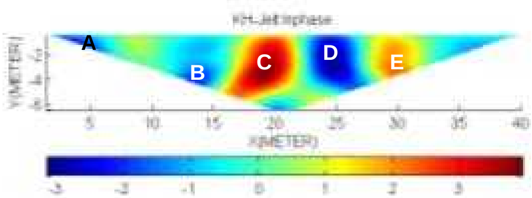

Figure 7. The Result of Karous-Hjelt Filter Line 3

We can identificate three conductive anomalies (A,B,D) and two resistive anomalies (C,E) in Figure 7. The inversion result is shown by Figure 8. The rms is 0.34. There are resistive anomalies at profil distance 16-30 meters, at depth 5 meters. The resistivity is 200-220 Ωm. These anomalies and Karous-Hjelt anomalies are the same. At depth 5-40 meters, the subsurface is dominated by material with resistivity 90-120 Ωm. Line 3 is different from Line 1 and Line 2, which in two lines before are dominated by more resistive materials than the materials in this line.

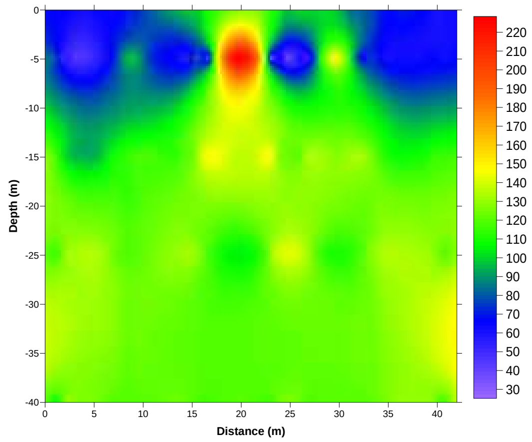

Figure 8. The Result of Inversion Line 3

- **Line 4**

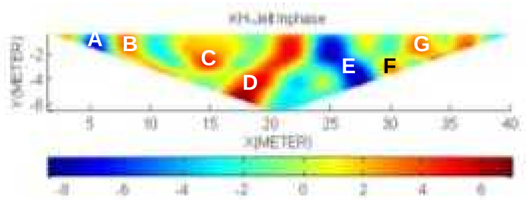

Figure 9. The Result of Karous-Hjelt Filter Line 4

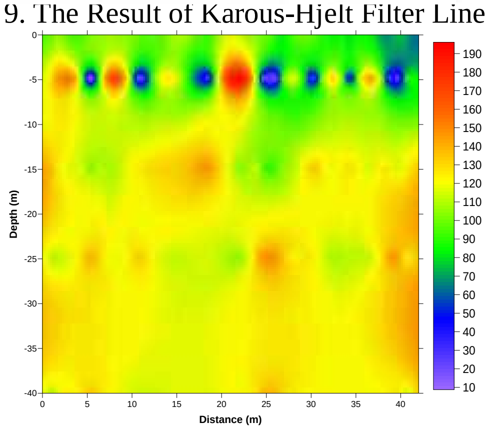

Figure 10. The Result of Inversion Line 4

In Figure 9, we can identificate two conductive anomalies (A, E) and five resistive anomalies (B,C,D,F,G). In Figure 10, there are some anomalies at depth 0-5 meters. The most resistive material is at profil distance ± 20 meters. This result is same as Karous-Hjelt Filter. At depth 5-40 meters, the subsurface is dominated by materials with resistivity 130-160 Ωm. The rms is 0.59.

The result of resistive anomalies in each line is supported by the observation that the selected lines in data recording across rocks as shown in Figure 21.

(a) (b)

Figure 21. The rocks that appear on the surface

CONCLUSION AND SUGGESTION

In each line, there are two types of anomalies are detected, the resistive anomalies which have higher resistivity values than the surrounding area and the conductive anomalies which have lower resistivity than the surrounding area. The resistive anomalies have resistivity 120-220 Ωm. They are estimated as an andesite. The conductive anomalies have resistivity 1-60 Ωm. They are estimated as the wet clay.

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