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Subsurface Structural Mapping Using 2D MT and Gravity Data of Dieng Geothermal Field, Indonesia

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ABSTRACT

Dieng Field is located in Central Java, Indonesia with 63 km2 of Concession Area. Dieng field also known as Vulcan Complex Area. About 47 wells have been drilled to prove potential geothermal resources of this field and able to generate electricity for Unit 1 (1x60 MW). For Unit 2&3 Development purposes, resource assessment has been doing in Dieng Field, including reservoir modeling and evaluation of surface & subsurface structural mapping. In this study, we attempt to evaluate subsurface structural pattern on this area using integrated interpretation of existing 2D MT and gravity data. The gravity survey of Dieng area is about 16 Km2 x 14 Km2 using approximately 371 gravity stations with 500 m spacing inside Dieng Concession Area and 1000 m spacing beyond. The MT survey of Dieng area is about 10 Km2 x 8 Km2 using approximately 285 MT stations and 173 TDEM stations. About 200 gravity stations and 100 MT & TDEM stations have been used for further evaluation regarding prospective area boundaries. For Gravity Analysis, second vertical derivative analysis is conducted to trace deep fault controlling Dieng area which results striking NW-SE, E-W and SW-NE. For MT Analysis, resistivity discontinuities and TE-TM curve splitting analysis are conducted to trace possible fault pattern from 2D MT Section which result striking NW-SE, E-W, NE-SW and N-S. Integrated subsurface structural mapping from both 2D MT and Gravity data combined with detail surface structural mapping will give us an understanding of structural play controlled Dieng Field.

1. INTRODUCTION

Dieng Field is located in Central Java, Indonesia with 63 km^2 of Concession Area. This Concession Area is owned by PT Geo Dipa Energi (Persero), an Indonesian geothermal State Owned Company (SOE). Resource estimation conducted using numerical methods by West JEC (2006) indicate that Dieng Field resource is 240 MW. Currently, Dieng Field is utilized for Unit 1, 1x60 MW of generating power plant. For Unit 2&3 Development, several production wells should be drilled to supply steam demand for power plant. According to this condition, resource assessment and evaluation has been done. Resource assessment activities consist of detailed structural mapping, reprocessing of geophysical data, and update reservoir modeling. This paper will explain about subsurface structural mapping using geophysical data such as 2D MT and gravity data as a part of resource assessment activity.

2. REVIEW OF GEOLOGY SETTING

Dieng Field is located in northeastern flank of North Serayu geanticline. N-S trending compression triggered uplifting of North Serayu zone caused geanticline trending E-W. This geanticline is become a weak zone and acted as a pathway for magma to rise upward during volcanism event in Late Pliocene. As a result, large amount of volcanoes trending E-W along North Serayu geanticline appears. Dieng Field is one of the volcanoes located in the northeastern-most of North Serayu geanticline. According to Miller et al (1984), Sukhyar et al (1986), rocks dating by Budihardi et al (1991) and Mapping by Nurpratama et al (2014), Stratigraphy of Dieng field consist of 3 (three) part, which are: 1) Older Dieng, 2) Mature Dieng, 3) Younger Dieng. The oldest rocks aged 3.9 Ma derived from Prau unit (Budihardi, 1991) and the younger rocks derived from Alluvial units. Structural geology of Dieng Field, according to Budihardi (1991) is dominantly trending E-W, NW-SE and NE-SW. On the other hand, the result from detailed structural mapping conducted by Nurpratama et al (2014) show that structural geology of Dieng Field controlled by 3 (three) major trend, which are: N-S, E-W, and NW-SE.

3. GEOPHYSICAL DATA ANALYSIS

Geophysical methods used to determine the condition of the subsurface geology by estimating the physical properties of the rocks below the surface, such as electrical properties, resistivity, conductivity, susceptibility, density, etc. There are two methods that been used in this study to identify subsurface structure, Gravity method and Magnetotelluric method

About 371 gravity stations are planted with 500 m spacing inside Dieng Concession Area and 1000 m spacing outside Dieng Concession Area to conduct gravity survey. After QC data has been conducted, only about 200 gravity data is used for further analysis. For structural geology interpretation, SVD analysis is conducted to extract structural geology from gravity data.

3.1. Gravity Method

Gravity method is a method to describe subsurface geological structures based on variations of the gravity field is shown by the difference in density between the rocks. This method can be used to determine the lateral position of the rocks which potentially has a high permeability. This method is a large measure of the force of gravity at the earth's surface, which in practice can be formulated as follows:

$$\mathbf{g = G \times M / R2}$$

g = force of gravity at the earth's surface (1m / sec2 = 105mGal)

M = mass of the earth (kg)

R = radius of the earth (m)

G = constant (6.67 x 10-11N.m2.kg-2)

Seen from the above equation that the greater the force of gravity at the earth's surface depends on the position of the center of the earth because pegukuran earth's surface morphology varied will give different distances to the center of the earth. However, in practice the greater the force of gravity measurement results can differ greatly from the results of the calculation. This is due to the existence of a zone of subsurface mass gravitational field that gave disturbance or called gravitational anomalies. This gravity anomaly can be used to estimate the condition of the subsurface structure of rock and so help to the interpretation of permeability in the area

3.2. SVD Analysis

One of the problems inherent within the interpretation of bouguer anomaly maps is that it is difficult to resolve the effects of shallow structure from those due to deeper-seated ones. The removal of the effects of the regional field from the bouguer anomaly data results is an indeterminate and non-unique set of residuals. It is possible to separate the probable effects of shallow and deeper structures by using Second Vertical Derivative (SVD).

The gravity field that measure by gravimeters varies with height; that is, there is a veretical gradient ($\frac{\partial g}{\partial z}$ = g'), over a non-uniform earth in which density varies laterally, the vertical gradient changes and the rate of change is thus the SVD of gravity field. This quantity is very sensitive to the effects of shallow features.

The Second Vertical derivative Method consists of calculating $\frac{\partial^2 g}{\partial^2 x}$ and $\frac{\partial^2 g}{\partial^2 y}$ using laplace equation

$$\frac{\partial^2 g}{\partial^2 x} + \frac{\partial^2 g}{\partial^2 y} + \frac{\partial^2 g}{\partial^2 z} = 0$$

SVD acts as a filter which sharpens the residual effects of the local horizontal and vertical gradient anomalies by removing the effects of regional (GETECH, 2007). Distribution based on SVD, Dieng geothermal area is limited by relatively high anomaly as though formed a circular boundary that covers all manifestations. SVD dominant anomalous values is zero (green color) that indicates the effect of bedrock which extends to a similar depth in the area of gravity investigation.

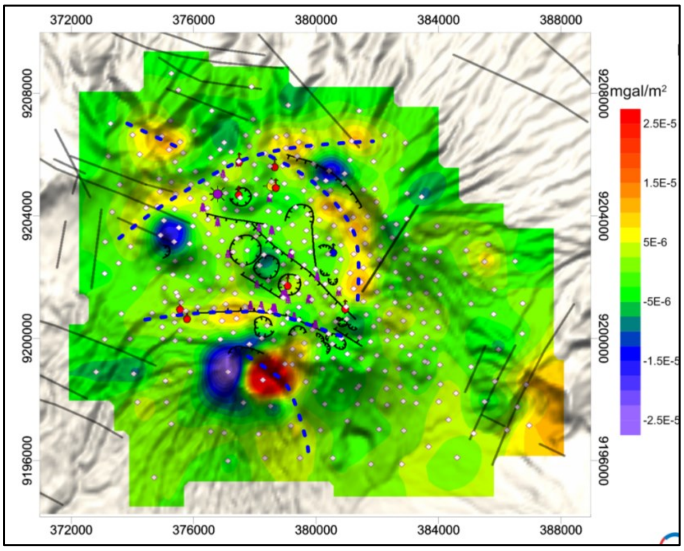

Figure 1: The result of SVD analysis. Blue line is interpreted structure geology.

3.3. MT Data Analysis

About 285 MT stations and 173 TDEM stations are planted to conduct MT and TDEM survey in Dieng Field. TDEM survey is conducted to support static shift analysis. After QC data has been conducted, only about 100 stations are used for further analysis. For structural geology interpretation, skin effect analysis is conducted for MT pseudo-section.

3.4. Static Shift analysis

Static shift is defined as a vertical shift of the resistivity curve, between the two curves (TE and TM) at the measurement stations, with no difference another in the form of curves, or phases. This problem must be addressed. If the not, it will lead to a misinterpretation of the data distribution of resistivity in below the surface, increasing the risk of drilling, and increasing the load exploration. There are several factors that cause static shift occurs, inhomogenitas near the surface, topography, and vertical contacts.

Static shift could also occur because there is no contact or vertical fault structure. We can see there is no contact between prisoners r1 and r2, where r1> r2. There are four stations, but the static shift does not occur at the station furthest from the vertical contacts may be caused by the accumulation of the charge has no effect on stasiun.Sementara at the station closest to the vertical contact, static shift occurs.

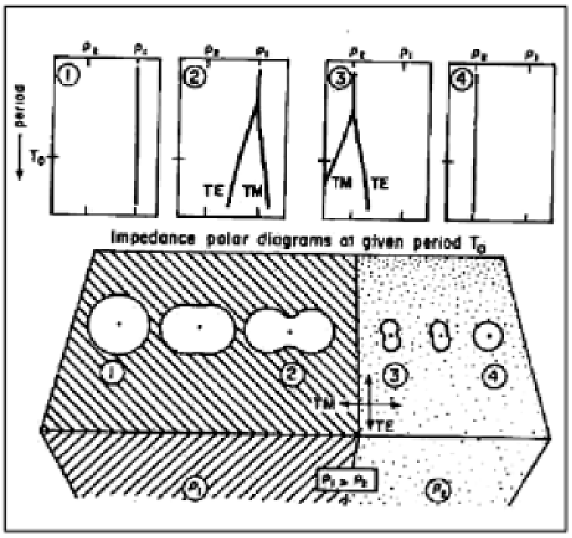

Figure 2: The simulation results on the measurement of the vertical contacts

MT Data is influenced by static effect like near surface heterogeneity, topography and vertical contact. This static effect should be corrected, otherwise will cause misinterpretation, increasing drilling risk and exploration cost. The static shift effect is a vertical offset of the entire MT profile that caused by isolated horizontal resistivity gradients near the surface. The TE and TM offset should be corrected using TDEM Data to constrain near surface resistivity. Other method is using geostatistics method.

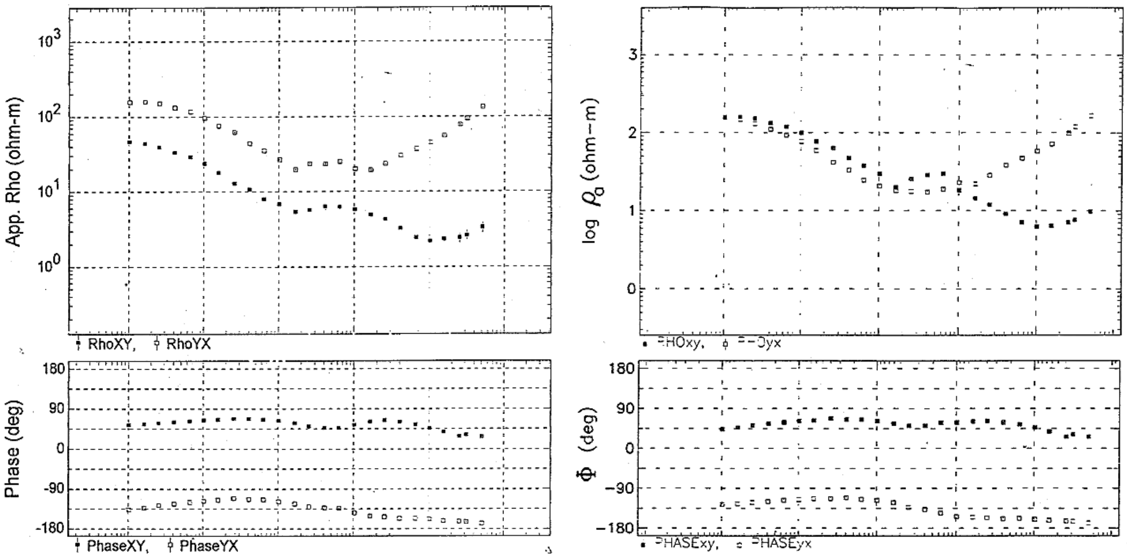

Figure 3: Before static shift (left), after static shift (right)

4.2 Skin Effect

As frequencies increase, conduction begins to move from an equal distribution through the conductor cross section toward existence almost exclusively near the surface. Skin effect is the exponential electromagnetic wave attenuation with depth. The depth in a homogenous medium at which the amplitude become 1/e of that at the surface called Skin Depth. In terms of MT method, the skin depth can be used to analyze the geology structure by analyze through TE and TM splitting curve. The splitting curve is visualize by resistivity discontinuity on 2D MT section. In normal cases it is well approximated as:

$$\delta = 503\sqrt{\frac{\rho}{T}}$$

where δ, ρ, and T are skin depth in meter, apparent resistivity in ohm.m, period in second.

Skin effect analysis could be applied in figure 3, one of MT pseudo-section example. In that figure, curve splitting started at ρ = 5.46 ohm.m, and T = 20.75 sekon. According to quotation above, skin depth value would be 3789 m. The beginning of curve splitting is interpreted as the beginning of displacement or structure geology. This method applied to 100 pseudo-sections derived from each MT station.

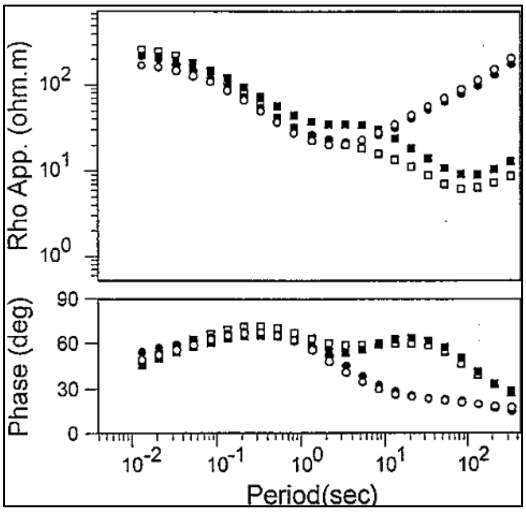

Figure 4: MT pseudo-section

It is still debatable though, the genetics of the curve splitting, whether controlled by structure geology, lithology contact, or alteration. By data support from SVD analysis and detailed surface structural mapping, we could categorize curve splitting derived from structure geology.

4.3. EFFECTIVE PENETRATION DEPTH

Effective Penetration Depth (D) is the depth that can be achieved when MT survey. The value of D can be written according to equation 2.9 (Vozoff, 1991).

$$D = 356\sqrt{\frac{\rho}{f}}$$

5. SUBSURFACE STRUCTURE INTERPRETATION FROM 2D MT AND GRAVITY

Subsurface structure interpretation is conducted by combine all the structural interpretation mainly from 2D MT with skin effect analysis and gravity with SVD analysis. On the other hand, the result of detailed surface structural mapping is used as main structural framework.

The result of SVD analysis in 200 gravity data (Fig.1) show 3 (three) major trend, which are: 1) NW-SE, distributed in northeastern part of Dieng Field, 2) NE-SW, distributed in northwestern part of Dieng Field, and 3) E-W, distributed in southern part of Dieng Field. On the other hand, skin effect analysis applied to 100 pseudo-section (Fig.4) data show 3 (three) major structural trending in Dieng Field, which are: 1) NNE-WSW, distributed in northwestern part of Dieng Field, 2) E-W, distributed in southern part of Dieng Field, 3) NW-SE, distributed in southeastern to northeastern part of Dieng Field.

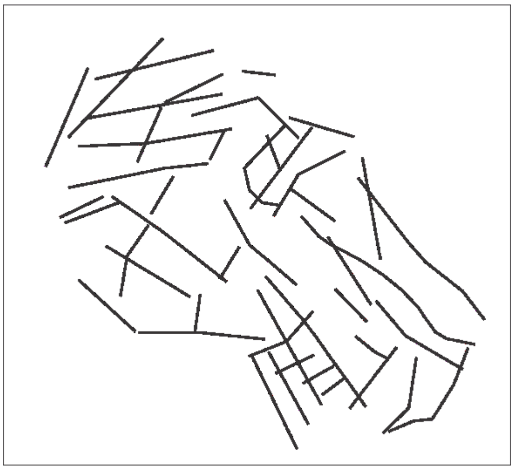

Figure 4: Structure geology interpretation from skin effect analysis to 100 pseudo-section data

The result of SVD analysis, 2D MT analysis and detailed surface structural mapping are being overlaid and some superimposed structure feature are found. This superimpose is worked whether between structure derived from SVD analysis and 2D MT analysis or from SVD analysis and detail surface structural mapping, or from 2D MT analysis and detail surface structural mapping, or even from those 3 (three) kind of structural analysis. The result of detail surface structural mapping gives us a confidence of main structural geology trend appeared in study area, yet it has a limitation of depth. Meanwhile, the result from SVD and 2D MT analysis give us more sense of deep structural play in study area. The combination of these 3 (three) kind of structure analysis will give us more comprehensive view in determining which fault is working on deeper depth. From the block feature in fig.5, shown that frequent superimposed structure taken place dominantly trending NE-SW and NW-SE, meanwhile superimposed structure trending E-W is less appeared. This means deeper structural plays tend to have NW-SE and NE-SW than E-W orientation. Considering that study area is a part of Serayu geanticline trending E-W, the E-W trending on southern part of study area is an anticline crest which has shallower normal faults, the NW-SE trending is a conjugate shear fracture which has develop to be deeper faults, and the NE-SW trending is a conjugate tension fracture which has develop to be deeper faults.

Figure 5: Overlay of structure geology interpretation derived from 2D MT (black line), SVD (blue line), and detailed surface mapping (red line)

5. CONCLUSION

Based on 2 (two) approaches method, which are: 1) 2D MT skin effect analysis, 2) Gravity SVD analysis and controlled the by result of detailed surface structural mapping, structural play in Dieng Field mainly trending in 3 (three) direction: E-W, NE-SW, and NW-SE. This result is also coherent with structural trending derived from detailed surface structural mapping. This result will gives a benefit in well targeting activities in the future.

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