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# Model Development Relating Electrical Resistivity to Mechanical Elasticity of Hydrothermal Aquifer at Geothermal Area of Panggo-Kaloling, Sinjai Regency, Indonesia

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## ABSTRACT

A mathematical model has been developed to obtain the relationship between two parameters of electrical resistivity and mechanical elasticity of subsurface rocks of the hydrothermal area of Panggo-Kaloling in Sinjai Regency.The model was developed using data exploration concerning of both methods from the area under consideration. Constructed model is able to relate a time travel of seismic waves propagation that stands for mechanical elasticity to electrical resistivity in the area. The characterictic properties of the relation show a close connection to the parameter of porosity of the subsurface rocks.  Comparing the results derived from the modeling with that of obtained from measurement gives suitable approximation with error level of less than 20%. The study concludes that the model is able to predict mechanical elasticity by using geo-electric method, or electric resistivity by using seismic refraction method.

*Keywords: porosity, electrical resistivity, mechanical elasticity, and travel time of waves propagation*

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## 1. INTRODUCTION

The increasing consumption of energy and demand of natural resources in the subsurface of the Earth lead to the increasing role of exploration. At the same time, scientific engineering for design and construction of infrastructures need more comprehensive information concerning the structure of bedrock. It is due to the facts that many buildings and roads have been damaged caused by the lack of information of soil properties where structures and building are constructed.

The exploration as well as exploitation of natural resources and structural mapping of subsurface rock is really required while environmental sustainability must remain guaranteed from the impacts.The Geophysical explorations are reasonably less priced and non -destructive method, and are the very potential for the exploration and mapping of the bed rock structure comprehensively. Nevertheless, geophysical explorations are of no absence of fundamental flaws. Consequently, careful activities duringexploration conducted need to obey precautionary principle.

Geophysical explorations are the common methods conducting in: (1) indirect measurement; (2) using limited number of parameters; (3) using more than one methods to obtain accurate results. The lesser methods we use the more effective and efficient works we conduct. Owing to this premis, we construct a transformation model that can link electrical resistivity to mechanical elasticit. parameters in exploring subsurface rocks as was previously developed by [1],[2],[3],[4]. Meju et al. [1] utilize the electromagnetic and seismic refraction methods for determine the correlation of electrical resistivity and seismic to adapted to near surface of the earth [5]. In this study their developed the relation of electrical resistivity and p wave velocity in linier relation. Ayolaby et al. [2] have been carried out of Igbogbo to determine the structure setting of the subsurface material and ground water potential without study the relationship between electrical and elasticity properties.. Ursin and Carcione [3] studied the cross properties relation between electrical conductivity and seismic velocity to determine the stiffness module and density expressing the porosity in terms of those properties. Jones and Eaton [4] studied the relationships of velocity – conductivity for mantle mineral assemblages. In this case he developed the relationship between the transversal velocity $v_s$ and conductivity. In this construct, mechanical elasticity will be represented by travel time of seismic waves propagation, and electrical resistivity represented from geo-electric measurement. Physical parameter which has connection to both parameters of electrical resistivity and mechanical elasticity will be selected to be porosity of the subsurface rocks as was developed by Hossain and Cohen (2012. The analysis will take benefit from the development of technology and information processing to help the process of interpretation. It is assumed that the porosity used in electrical and mechanical properties remains the same for both purposes. Based on this assumption, the transformation model will be develop .

The study aims: (1) to explore electrical and mechanical properties of the sub-surface rocks in the hydrothermal area; (2) to relate mathematically parameter of electrical resistivity to parameter of mechanical elasticity.

## 2. MATERIALS AND METHODS

Data were collected at the hydrothermal area of Panggo-Kaloling, Sinjai Regency, Province of SouthSulawesi, and performed by the method of electrical resistivity by using geo-electric method together withmechanical elasticity by using the method of seismic refraction. The focus of study cover the stretching of ranges from is 90 m to 100 m lengths. Other important parameter to find is the porosity of the subsurface rocks under studied. The Schlumberger and Wenner configurations are used to set up the pattern of probes to figure out the vertical profiles of electrical resisitivity of the subsurface rocks. The Schlumberger configuration is set up at four corners to determine the condition of resistivity, while the Wenner configuration is set up on four sides to determine the nature of resistivity in 2-dimensional profiles of vertical layers. It is believed that from the facts reported by Hossain and Cohen (2012) that the porosity ($\emptyset$) will be an important parameter that linked the elctrical resistivity to the mechanical elasticity of the rock under studied. If it is assumedthat the time travel ($t_p$) of seismic waves propagation is a function of porosity $\phi_r$ that can be written as:

$$t_p = f(\phi_r) \quad (1)$$

Similar to that of (1), the resistivity ($R$) is a function of porosity $\emptyset_e$ that takes the form as:

$$R = g\,(\emptyset_e) \quad (2)$$

If the both explorations involve geo-electric and seismic methods at the same area then we have:

$$\phi_r = \phi_e = \emptyset \quad (3)$$

The travel time of propagation per unit length can be written as:

$$t_p = f\{g^{-1}(\phi)\} \quad (4)$$

It has been proven that the relation between porosity $\emptyset_e$ and electrical resistivity takes the form as:

$$\emptyset_e = \left(\frac{R_f}{R_o}\right)^{1/m}\left(\frac{R_M-R_o}{R_M-R_f}\right) \quad (5)$$

Equation (5) shows that $R_o, R_f,$ and $R_M$ respectively stand for measured resistivity, fluid resistivity that filled the rocks and resistivity of rock matrix, $m$ is cementation factor. While from seismic exploration method, we can find the relation between porosity $\phi_r$ with the time of wave propagation per unit length which is given by:

$$\emptyset_r = \frac{(t_p-t_M)}{(t_f-t_M)} \quad (6.a)$$

In other formulation, we will have also the form of:

$$t_p = \emptyset_r t_f + (1-\emptyset_r)t_M \quad (6.b)$$

Equation (6.b) shows that $t_p, t_f,$ and $t_M$ respectively are the measured travel time of propagation, travel time of propagation in fluid, and travel time of propagation of rocks matrix per unit length. The important way to find out the standard model for subsurface rocks is to measure the resistivity at the same area in time andequal conditions for both exploration methods of electrical resistivity and mechanical elasticity. For both methods, the porosity of subsurface rocks is of importance to have equal values whether for the measurement of electrical resistivity as well as for mechanical elasticity. Substitute the equation (5) into the equation (6.b) we will have:

$$t_p = AR^{-\frac{1}{m}} + B\,R^{\frac{m-1}{m}}C \quad (7)$$

Constants in equation (7) are written as follows:

$$A = \frac{R_f^{\frac{1}{m}}R_M}{R_M-R_f}\left(t_f-t_M\right) \quad (8.a)$$

$$B = \frac{R_f^{1/m}}{R_M-R_f}\left(t_M-t_f\right) \quad (8.b)$$

$$C = t_M \qquad (8.c)$$

The relationship between $t_p$ and $R$ can be obtained by calculating the constants of *A*, *B* and *C* of equations (8.a, 8.b, and 8.c) using the method of least square as performed by Petras and Bednarova (2010).

## 3. RESULTS AND DISCUSSION

### *A. Geo-electrical Resistivity Measurement*

Measurement using Schlumberger's configuration: covering 4 sounding points successfully has identified 4 (four) layers which is reduced into3 (three) layers of subsurface rocks. In each figure 1.a to 1.d, the vertical axis is resistivity, horizontal axis is electrode space;where° = resistivity, h = thickness, d =depth, Alt = altitude; Coulor form bottom to upper layers indicates as apparent resistivity .

*Sounding 1.*

The first sounding depicted in Figure 1.a discovers layer (1) having 23.2Ωm of resistivity with 0.864 m of thickness is identified as overburden ; layer (2) having 142Ωm of resistivity with 1.14 m of thickness. is interpreted as volcanic tuff ; and layer (3) having 6.84Ωm with 14.5 m of thickness which is identified as an aquifer of hydrothermal zone.

*Sounding 2*

The second sounding depicted in Figure 1.b discovers layer (1) having 12.8 Ωm of resistivity with 0.26 m of thickness is identified as overburden layer; layer (2) having. 628Ωm of resistivity with 1.14 m is identified as volcanic tuff, the aquifer of hydrothermal zone is found in the fourth layer

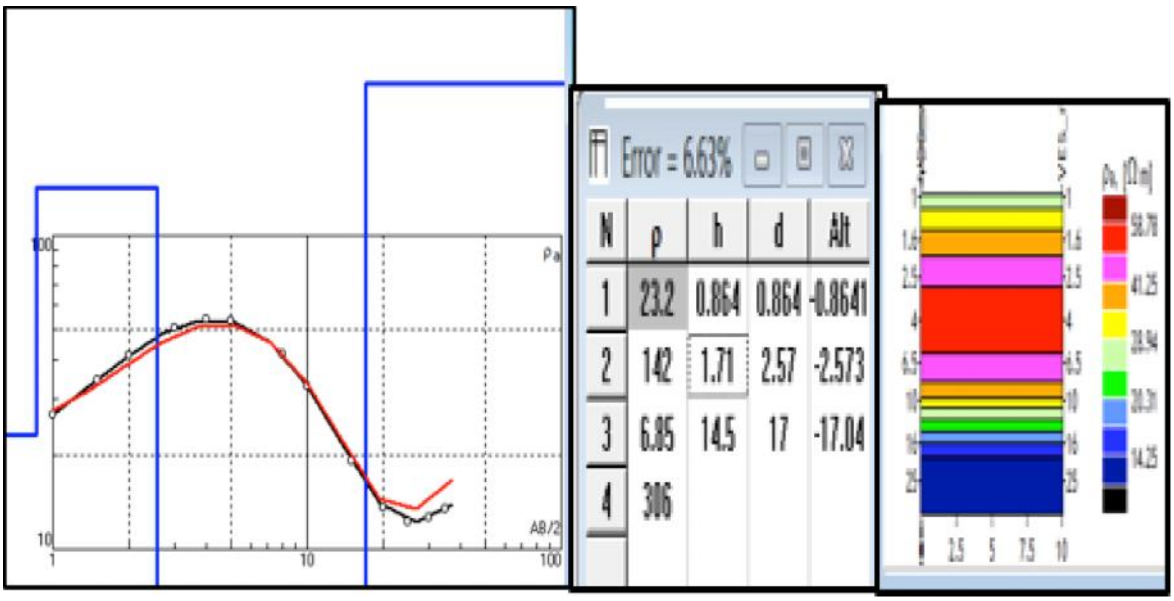


Figure 1.a The first sounding of Schlumberger configuration with its sounding Profile

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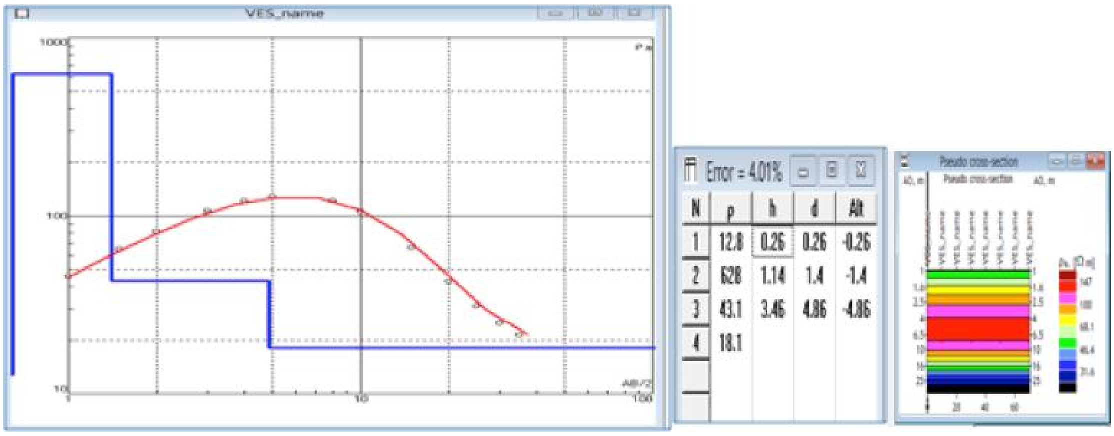


Figure 1.b The second sounding of Schlumberger configuration with its sounding profile

The third sounding depicted in Figure 1.c discovers layer (1) having 5.8 Ωm of resistivity with 0.585 m of thickness identified as overburden layer; layer (2) having 482 Ωm with 0.59 m of thickness identified as the volcanic tuff ; and layer (3) having 5.034Ωm with 1.01 m of thickness which is identified as an aquifer of hydrothermal zone.

*Sounding 3*

The third sounding depicted in Figure 1.c discovers layer (1) having 5.8 Ωm of resistivity with 0.585 m of thickness identified as overburden layer; layer (2) having 482 Ωm with 0.59 m of thickness identified as the volcanic tuff ; and layer (3) having 5.034Ωm with 1.01 m of thickness which is identified as an aquifer of hydrothermal zone

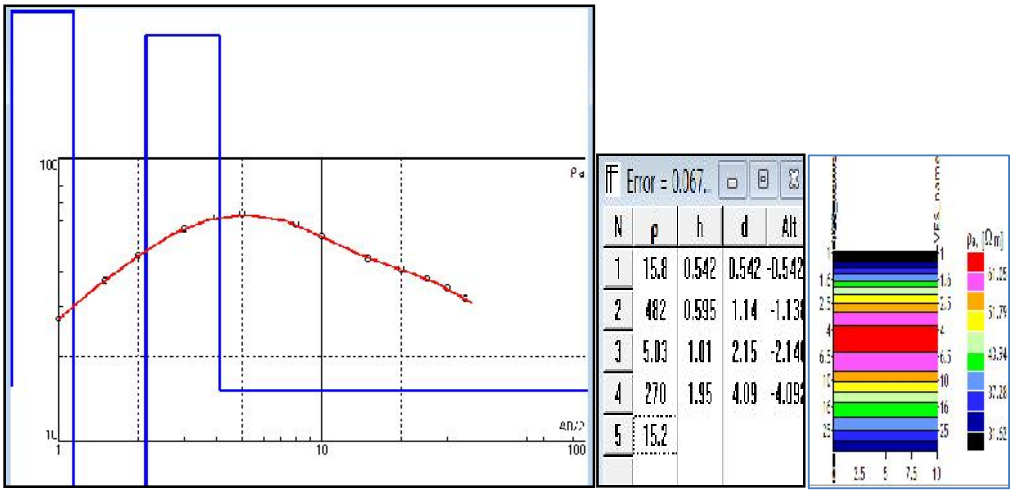


Figure 1.c The second sounding of Schlumberger configuration with its sounding profile

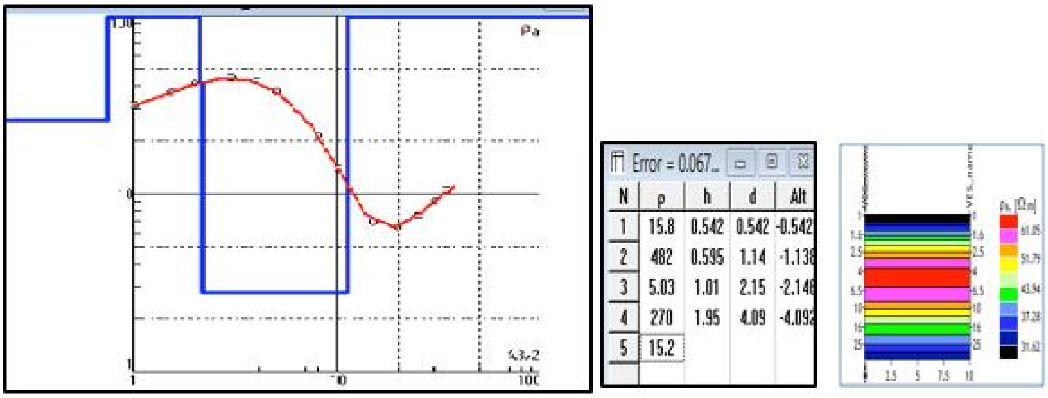


Figure 1.d The third sounding of Schlumberger configuration

*Sounding 4*

The fourth sounding depicted in Figure 1.d discovers layer (1) having 25.8Ωm with 0.4 m of thickness identified as overburf=den layer identifiwe as overburden layer; layer (2) having 103Ωm with 1.72 m of thickness identified as volcanic tuff; and layer (3) having 42.7 Ωm of resistivity with 0.82 m of thickness asthe aquifer of the fourth sounding.

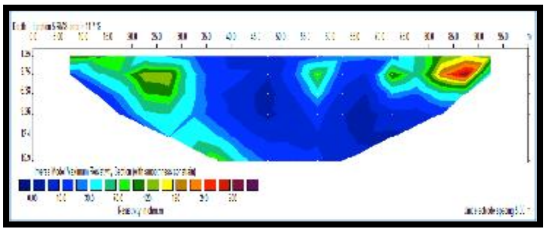

Figure 2.a The first line of Wenner configuration

discovered from all soundings show high resistivity with the thickness of about 0.8 m to 1.5 which can be identified as the rocks of volcanic tuff.

*B. Measurements using Wenner's configuration*

The results of this configuration are depicted in Figure 2.a, Figure 2.b, Figure 2.c, Figure 2.d, and Figure 2.e and give the profile of vertical layers which are generally also showing 3 (three) types of rocks resistivity. Those are layer (1) with 15 Ωm of resistivity, layer (2) with resistivity greater than 100 Ωm, and layer (3) as an aquifer zone with resistivity small than 10 Ωm. In these measurement is identified three types of subsurface as overburden layers (green) , the volcanic tuff (yellow and red) and the hydrothermal zone (blue).

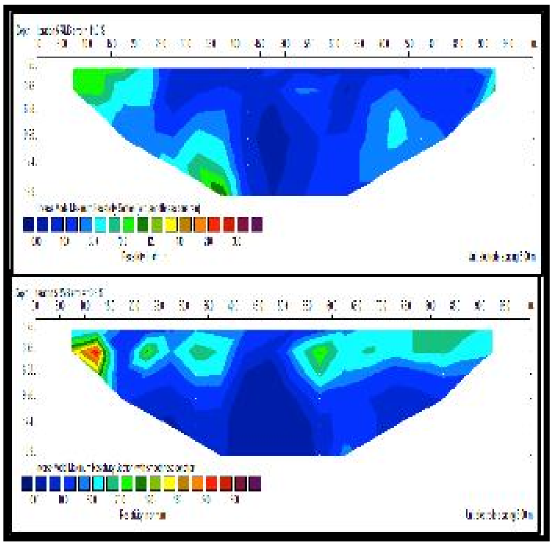

Figure 2.b and 2.c The second line and the third line of Wenner configuration

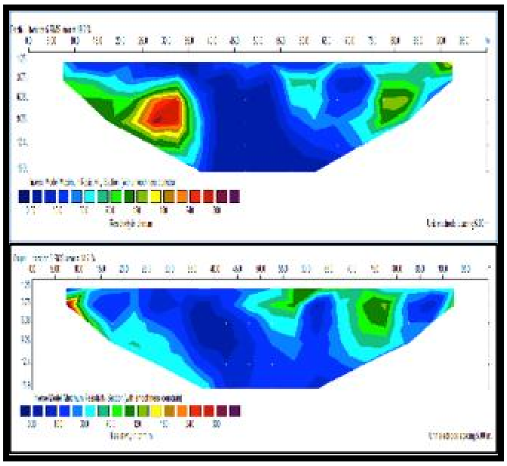

Figure 2d and 2.e The fourth line and the fifth line of Wenner configuration.

C. Seismic Interpretation

The relationship between electrical resistivity with mechanical elasticity which is represented by travel time of wave propagation of subsurface rockshas been completed by using both exploration methods of geo-electric and seismic measurements. Seismic data acquisition is done and performed in the same location and condition that of the geo-electric measurement.The results give us with six trajectories of exploration which are carried out on each side of the hydrothermal area. The analysis and interpretation of seismic data are conducted usingtomography of seismic method by which the results depicted in more detail profiles. Velocity profiles in the four trajectory measurements are described in Figure 3.a-Figure 3.f below

The results have identified three layers of propagating velocity of P-waves. Those are layer (1) having velocity of 200 m/s, layer (2) having velocity of 400 m/s, and layer (3) having velocity of 600 m/s. There six trajectory measurement seismic realized in this study. At all of trajectory there are the shallow depths of hydrothermal zone (green) color. In to six the such easurement identified the fault zone. These faulting are estimated as a source of the emergence of geothermal systems.

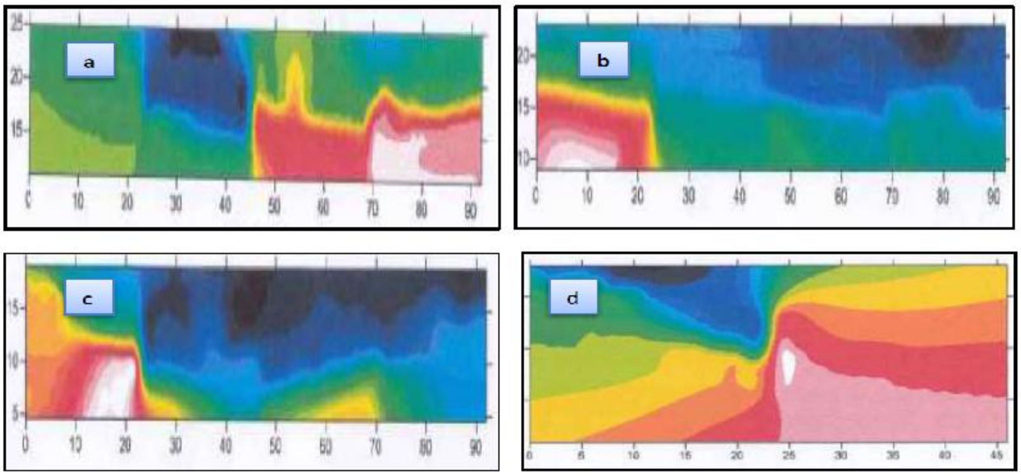


Figure 3a. velocity profile in a,b,c and d trajectories seismic

*D. The Relationship of Electrical Resistivity to Mechanical Elasticity*

Solving equation (7) using the method of least squares numerically approximated by finite differences as was performed by least square method resulted in four curves that describe the relationship between mechanical elasticity with electrical properties as depictedin Figure 4.a, Figure 4.b, Figure 4.c, Figure 4.d Figure 4.e, Figure 4.f below. The fourth of these relation are:

1. Relation of velocity of wave propagation with conductivity as
2. Relation of velocity of wave propagation with resistivity.
3. Relation of time propagation/unit length with conductivity
4. Relation of time propagation/unit length with resistivity

## 4. CONCLUSIONS

The analysis and interpretation of the data measurement confirm the mathematical models being developed. The velocity of waves propagation as a function of conductivity or resistivity. Therefore when one of the both physical parameters of the rock is obtained, then the other parameter can be calculated using the model.

## 5. ACKNOWLEDGEMENTS

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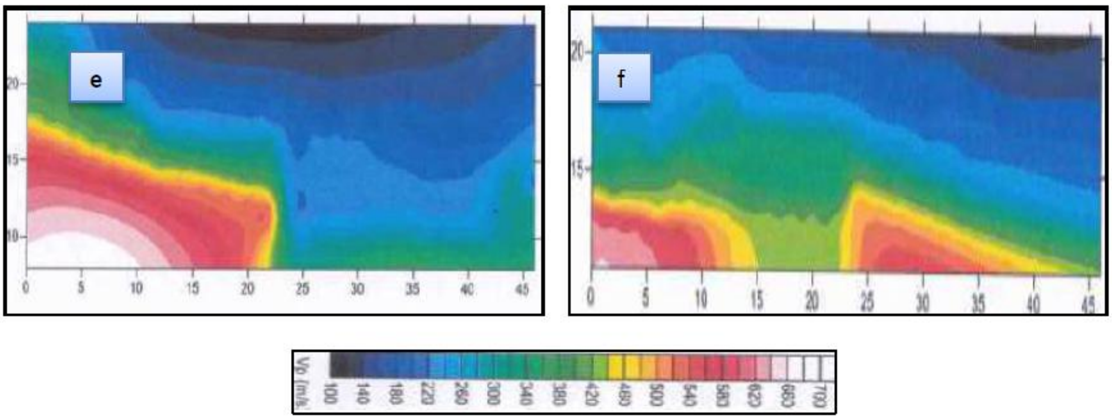
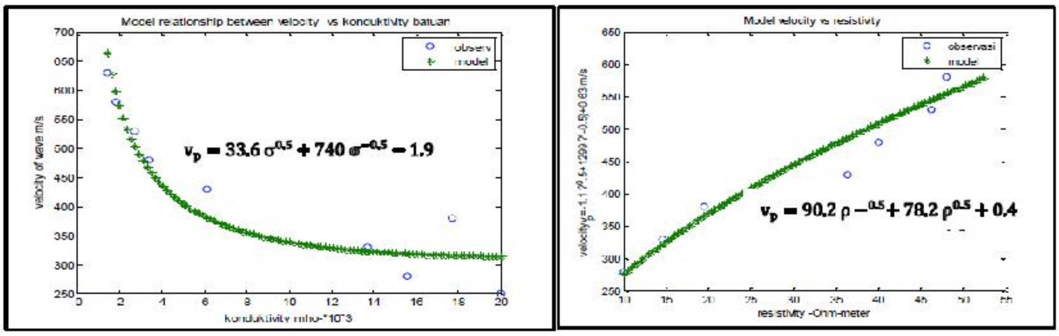
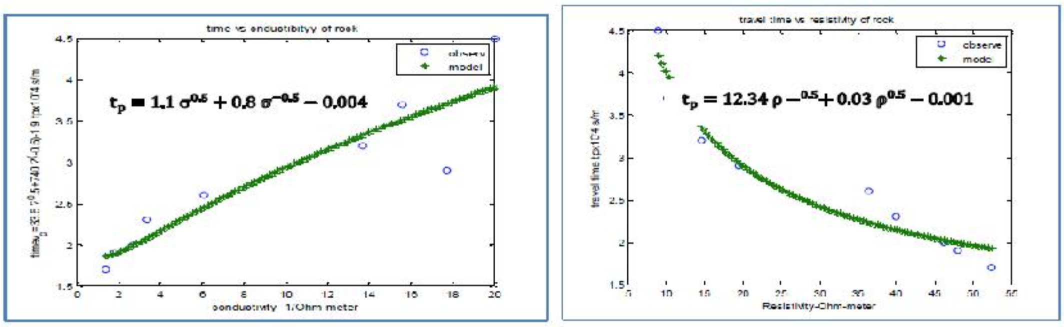



Figure 3b velocity profile in e and d trajectories seismic




(a) (b)

Figure 4 (a) Relation of velocity of wave propagation with conductivity, 4(b) Relation of velocity of wave propagation with resiativity




(c) (d)

Figure 4 (c) Relation of time propagation/unit length with conductivity, 4 (d) Relation of time propagation/unit lengt with with resistivity

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