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Application of Tomography Inversion Methods to Determine the Seismic Wave Velocity Structure (Vp, Vs, Vp/Vs) of the MEQ Data on "ALPHA" Geothermal Field

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ABSTRACT

Micro earthquake occurred due to of hydraulic fracturing process in a geothermal field. Six array seismometers installed in "ALPHA" geothermal field and during the period of July 2012 to December 2012 recorded 133 micro earthquake event's (MEQ). P and S wave travel time of MEQ data relocated earthquake simultaneously and calculated 3-D velocity model. P wave velocity (Vp) and S wave velocity (Vs) also has been compared to the velocities through the process of Tomography inversion. Tomography inversion output are cross section of the velocity model Vp, Vs and Vp/Vs, then it will be a basis of the analysis to identify the state of the subsurface in "ALPHA" geothermal field. Result of inversion model was indicated that "ALPHA" geothermal field has 10 until 15 layers of rock with different in Vp and Vs. The elevation range 580 m to 1100 m was interpreted as a zone of cap rock and an impermeable layer with P wave velocity (Vp) between 2,615 km/s until 3,051 km/s. Another result in order to value of the ratio Vp/Vs is relatively low between 1,7 until 1,8 at depth of 1 km until 2 km from velocity model. The ratio value was analyzed as a layer of low ranging from 1,6 to 1,807 on the tomogram velocity model, than it is analyzed as a coating zone associated with *gas-saturated rock* and "ALPHA" geothermal field indicated steam dominated of geothermal filed type.

1. INTRODUCTION

Micro earthquake phenomenon occurred due to of exploitation and recharge processes in a geothermal field. The resulting micro earthquake can provide important information about the state of the reservoir and subsurface structure, including the P wave and S wave velocity structure (Vp, Vs and also Vp/Vs). Seismic velocity is one of the good physical parameters to describe the characteristic of the subsurface medium caused by the interrelatedness between the distributions of velocity with subsurface lithology structure. Modeling of P wave Velocity (Vp), S wave Velocity (Vs) and ratio between the two wave (Vp/Vs) of seismic waves using micro earthquake data will be very useful in the area of geothermal to observe the changes that occurred in the conditions of the geothermal reservoir through the description and analysis velocity data on results of inversion tomography process.

Micro earthquake data used in this study is the results of field data recording MEQ in "ALPHA" geothermal field during the period July 2012 to December 2012. From 133 events were recorded during the period, obtained travel time data with 446 phase P and 448 Phase S. the travel time data that will be input in the subsequent data processing.

2. BASIC THEORY

Micro earthquake is a low magnitude earthquake caused by several things, such as hydrocarbons are produced, injection of fluids into the geothermal reservoir and so on. Generally, micro earthquake may occur due to weak zones that are open or shifting of water injected continuously resulting in increased pressure in the rocks, contact between the cold water with hot igneous and reduced pore pressure due to fluid production.

Seismic tomography is a method to reconstruct the structure of the earth's subsurface using waveform data or travel time data of seismic waves. This method is used to obtain a detailed profile of the distribution of physical properties of rocks such as slowness.

The basic concept of seismic tomography is the data taking into account the travel time of the wave. Travel time is shown by the equation:

$$t_j = \tau_i + T_{ij} \dots\dots\dots (2.1)$$

And the travel time between the sources i and j monitoring stations can be formulated by the equation:

$$T_{ij} = \int_{L_{ij}} s(r)dl \dots\dots (2.2)$$

Where the slowness as a function of position has the equation:

$$s = \frac{1}{v} \dots\dots\dots\dots\dots (2.3)$$

With t_j is the arrival time at the j observer station, τ_i is the time of the earthquake from source i (origin time), T_{ij} is the travel time between the source i and j observer station, s(r) is the slowness and V is the velocity of seismic waves.

In this study, the algorithm adapted to parameterize the model used so that the calculation is based on the equation:

$$t_j = \sum_{i=1}^{n} s_i dl_{ij} \dots (2.4)$$

The above equation is decomposed into simultaneous linear equations parameterization according to the conditions in the study, so it will form a matrix equation which contains the travel time, the kernel matrix that contains the ray path length and matrix containing the slowness parameter, which is a matrix of parameters that we want to know.

3. METHOD

The research method in this study is a descriptive analytic study which includes literature, data processing and analysis and then interpretation. Data processing and tomographic inversion process performed using the software Local Tomography Software release 12 (LOTOS 12) made by (Ivan Koulakov, 2012). The following flow chart of research in general:

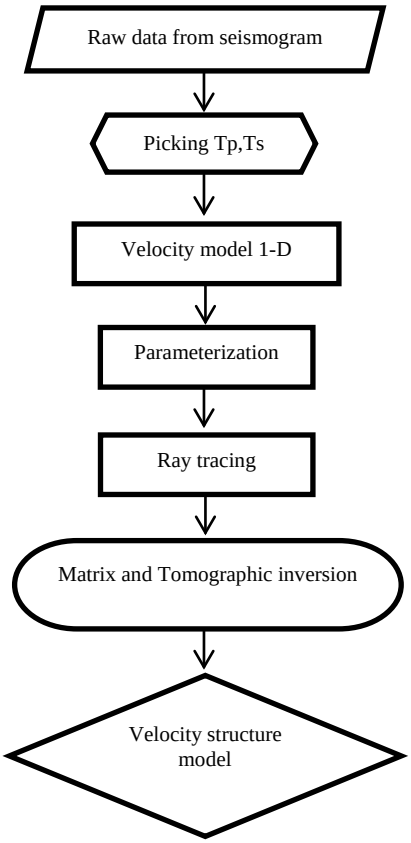


Figure 3.1 flow chart of research in general

Table 3.1 velocity model 1-D

layer	velocity (km/s)	Thickness (km)
1	2,95	0,5
2	3,20	0,2
3	3,50	0,3
4	3,82	0,5
5	4,50	0,5
6	4,80	0,9
7	5,80	2,5
8	6,70	20,0
9	8,00	30,0

4. RESULTS AND ANALYSIS

4.1 Hypocenter Distribution

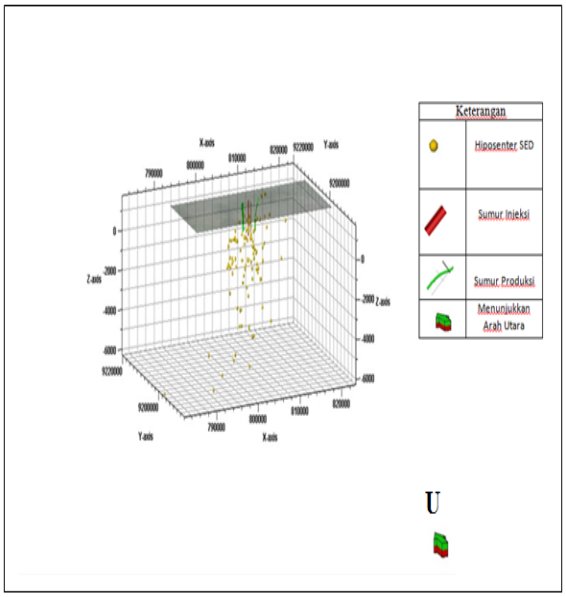


Fig 4.1 hypocenter distribution results in "ALPHA" geothermal field viewed from the south

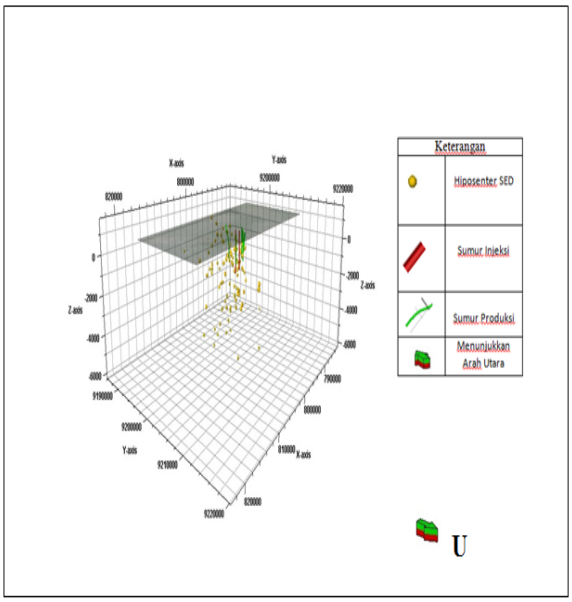


Fig 4.2 hypocenter distribution results in "ALPHA" geothermal field viewed from the north

4.2 Subsurface Velocity Model

In this research, previous authors make cross-sectional area surrounding the “ALPHA” geothermal field. The author makes 4 cross sections that are considered representative of the entire area covered and the geothermal field. Here is a cross section at this research:

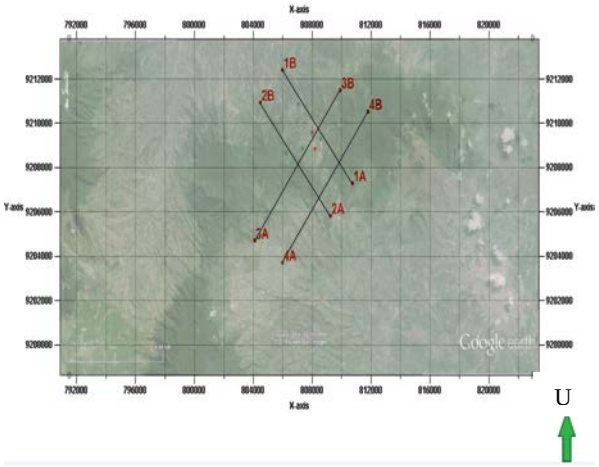


Fig 4.3 trajectory sectional area of research. Red and green dots on the map show the injection wells and production wells.

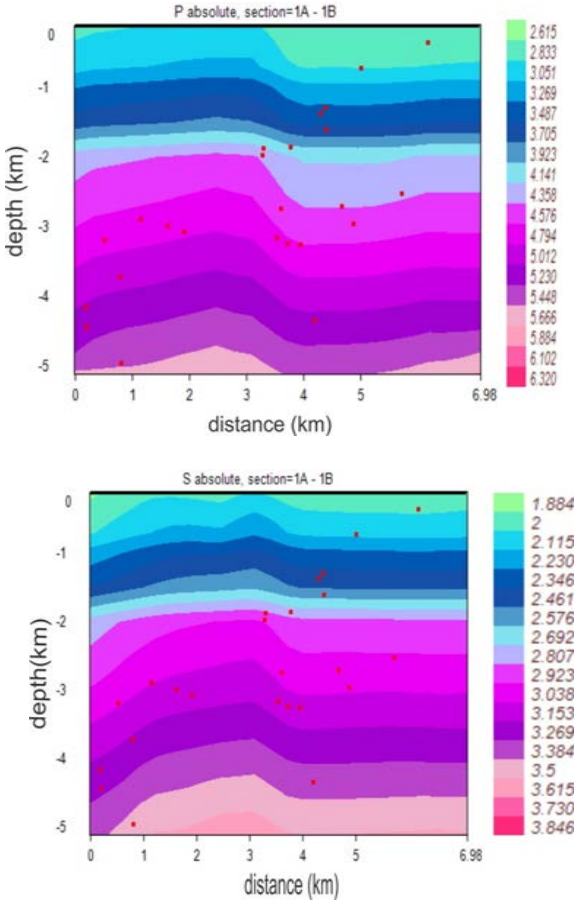
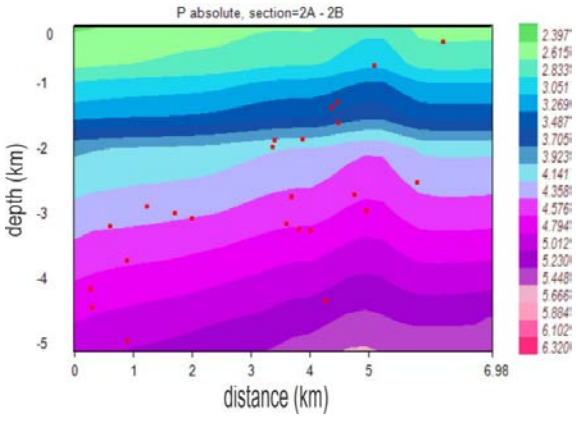


Fig 4.4 horizontal cross-sectional tomogram P wave velocity (Vp) and S wave (Vs) trajectory 1A-1B. red dots indicate events recorded by seismometers.



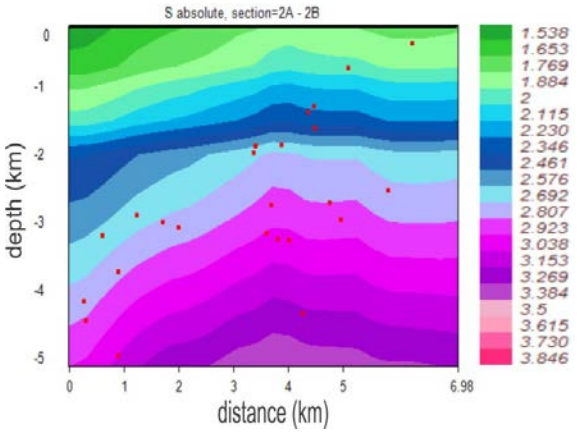


Fig 4.5 horizontal cross-sectional tomogram P wave velocity (Vp) and S wave (Vs) trajectory 2A-2B. red dots indicate events recorded by seismometers.

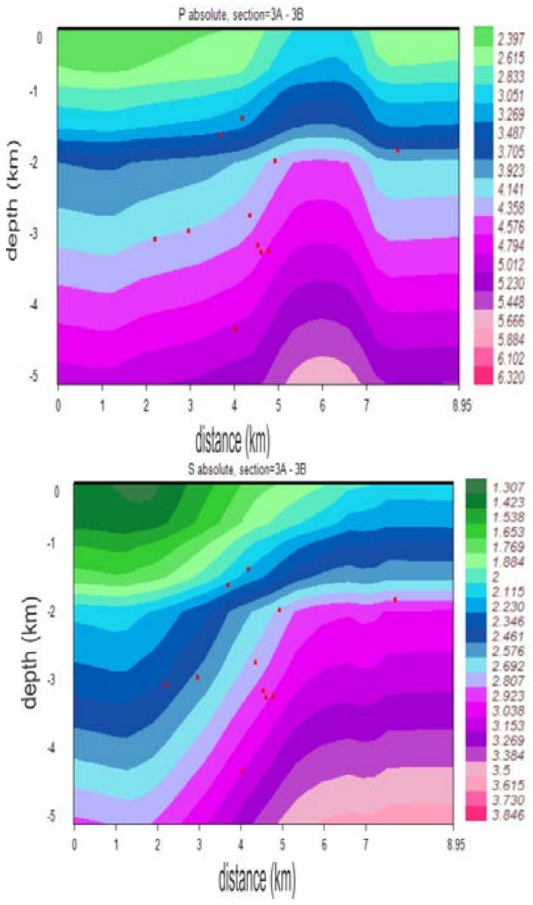
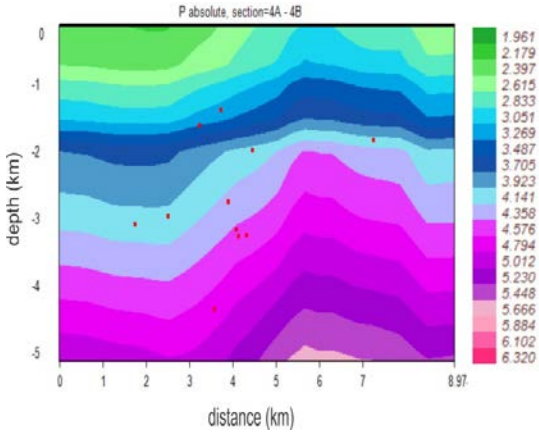


Fig 4.6 horizontal cross-sectional tomogram P wave velocity (Vp) and S wave (Vs) trajectory 3A-3B. red dots indicate events recorded by seismometers.



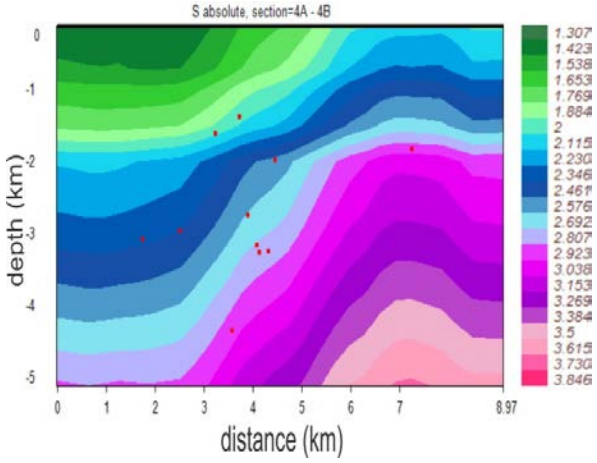


Fig 4.7 horizontal cross-sectional tomogram P wave velocity (Vp) and S wave (Vs) trajectory 4A-4B. red dots indicate events recorded by seismometers

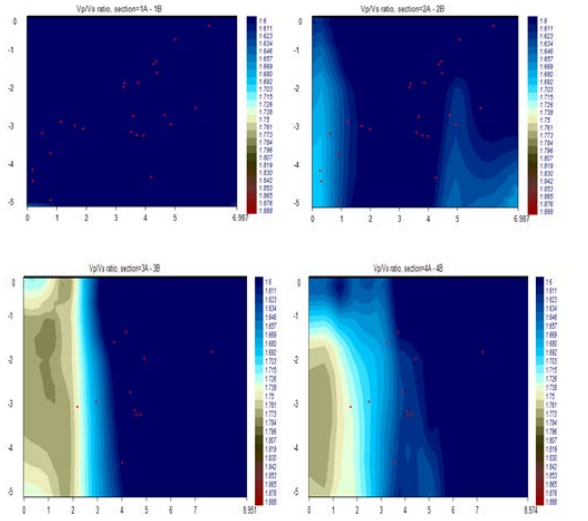


Fig 4.8 tomogram velocity model vertical cross section ratio Vp / Vs

Tomographic inversion results in LOTOS 12 has two basic output. The basic output are structure of P wave Velocity (Vp) and S wave velocity (Vs) and then relocation of the micro earthquake hypocenter in the study area. Fig 4.5 to 4.7 show relocation of hypocenter (red dots) and tomogram velocity model (Vp and Vs). Having acquired the structure velocity (Vp and Vs) results tomographic inversion proses, further calculation ratio Vp / Vs, as shown in Figure 4.8. value of the ratio Vp / Vs is used in the analysis process to interpret "ALPHA" geothermal field conditions

4.3 Analysis

From the results of plotting the distribution of the hypocenter (fig 4.1 and 4.2) can be interpreted that the earthquake hypocenter (micro earthquake hypocenter) was at a depth of 0-2000 m and widely spread around the injection wells and production wells. it is caused in that area is an area of the initial formation of micro earthquakes by fluid injection continuously on injection wells and steam extraction on production wells.

When fluid is injected at a geothermal field, the fluid will flow to areas of high-temperature rock. So that the fluid will fill up the spaces in the rock. And then the fluid injection volume will be increase so give a significant pressure on the rock that will ultimately result in the phenomenon of micro-earthquakes. It is reasonable that the micro earthquake hypocenter at "ALPHA" geothermal field concentrated around the injection wells and production wells.

As for the micro earthquake hypocenter located far from the injection wells and production wells can be caused by several things like fluid injection activities from the other geothermal field located around "ALPHA" geothermal field or seismic activity of Kendal Mountain.

Based on result of Tomographic inversion process using LOTOS 12 (fig 4.4 to fig 4.7), That "ALPHA" geothermal field consists of 10 until 15 structure of the rock layers to a depth 5 km below the surface with different in Vp and Vs. the P wave velocity (Vp) measured ranged from 2,397 to 5,666 km/s and S wave velocity (Vs) ranged from 1,423 to 3,864 km/s where the deeper the wave velocity was greater. The micro earthquake events that are more visible in the top layers of rock between 0-3 km below the surface and consistent with our previous discussion regarding the hypocenter distribution of "ALPHA" geothermal fields. Based on lithology obtained from well data, at a depth of 53 m to 1500 m rock formation layers are generally dominated by breccia tuff and andesite altered.

Based on tomogram P velocity model trajectory 3A-3B, there are zones with relatively low Vp values ranging from 2,615 to 3,051 km/s at a depth of -0.5 s / d -1.2, that analyzed a clay cap layer (*up doming structure)* and the authors interpret as a cap rock layer of geothermal reservoir in "ALPHA" geothermal field.

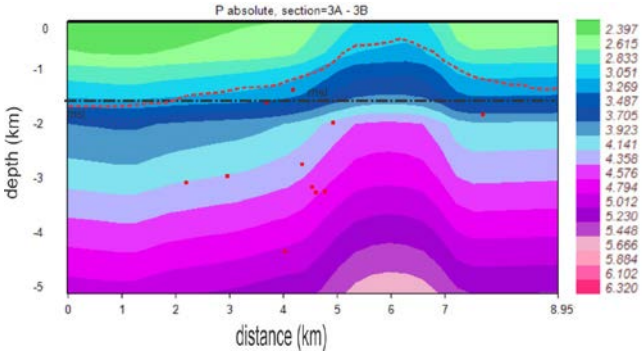


Fig 4.9 analysis of cap rock on the vertical cross section 3A-3B

The existence of zones of clay cap (*up doming structure)* that is suitable with a previous research conducted by Anjar Oktikawati (2013), and then generally has a pattern similar to the resistivity structure of Magnetotelluric data from the management company of "ALPHA"geothermal field.

The existence of zones with very high temperatures in the subsurface layers in a geothermal field will give the effect of varying the value of Vp and Vs. so that the variation of Vp and Vs values will give the value varies also on the value of the ratio Vp/Vs. on the state of the *gas-saturated rock* Vp and Vs values liable to decrease with a more significant decline in Vp compared to Vs decrease, so will result in the value of the ratio Vp / Vs is relatively low. In contrast to the state of the *water-saturated rock* Vp and Vs values liable to decrease it's the same thing on the state of the *gas-saturated rock* but in these circumstances (*water-saturated rock*) decline in Vp values liable to be lower, so will result in the value of the ratio Vp / Vs are likely to be higher than the state *gas-saturated rock*.

The results of the ratio Vp/Vs value from tomographic inversion process at LOTOS 12 for "ALPHA" geothermal field tend to be low ranging from 1.6 to 1.807. Based on the situation the authors interpret that the geothermal reservoir in "ALPHA" geothermal field contained in the zone associated with the *gas-saturated rock* , this indicates that the geothermal field with this characteristics including steam geothermal field dominance (steam dominated). And also this is suitable with previous research conducted by utami (2000) on "ALPHA" geothermal field.

5. CONCLUSION

Based on the data recording of MEQ in "ALPHA" geothermal field and process of tomographic inversoin using LOTOS release 12, produce good tomogram velocity model for P wave velocity (Vp), S wave velocity(Vs), and comparison between P wave velocity and S wave velocity (Vp/Vs) in trajectory 1A-1B, 2A-2B, 3A-3B and 4A-4B. Based on ratio Vp/Vs Value in this research the authors interpret that the geothermal reservoir in "ALPHA" geothermal field contained in the zone associated with the *gas-saturated rock* , this indicates that the geothermal field with this characteristics including steam geothermal field dominance (steam dominated).

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