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# MICROEARTHQUAKE MONITORING IN "AFA" GEOTHERMAL FIED: MICROEARTHQUAKE ANALYSIS, DETERMINATION HYPOCENTER, STATION CORRECTION, AND 1-D SEISMIC VELOCITY

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## ABSTRACT

Microearthquake monitoring is one of geophysical method that can be used to determine fluids injection movement and subsurface physical properties (seismic velocity and attenuation). One of microearthquake characteristic is high frequency content, based on this study frequency content of microearthquake (2-66 Hz) is higher than regional earthquake (0.6-10 Hz). Hypocenter determination of microearthquakes of Mount "AFA" has been conducted by GAD method (Geiger's method with adaptive damping). After that, we then determine 1-D seismic velocity model using coupled velocity-hypocenter method. Coupled hypocenter-velocity method is a method of relocating earthquake, 1-D seismic wave velocity model determination and correction stations simultaneously using the principle method of Geiger. Result from 1D velocity model show low Vp/Vs ratio at depths of -0,2 to 0,8 km. Our interpretation is this anomaly may be related to a rock layer which is saturated by vapor (gas or steam). With station correction we can interpret material condition around station. If the values of station correction are low it is indicated that material condition around station is more massif than another area.

## INTRODUCTION

Volcanic activity and plate movement can be determined by distribution of earthquakes location. Besides that, distribution of earthquakes location can be used for geothermal reservoir monitoring especially for microearthquakes. Hypocenter determination of microearthquakes is influenced by geometry monitoring stations, error arrival time reading, phase waves availability, and geological structure knowledge in the study area (Gomberg et al, 1990).

Before we determine hypocenter location, we have to identify first what kind of earthquake it is. Most of microearthquake have low difference arrival time of P and S waves and have higher frequency content than regional earthquake. To determine hypocenter location we have to make inverse modeling. Inverse modeling method aims to find a position that has minimum value from observation and calculation arrival time data (minimum global). Inverse modeling is basically a modeling technique with trial and error and modifies model parameters to obtain minimum values of observation and calculation data. We used linear inversion using Geiger's method to determine travel time calculation data faster. In the reality there is weathering layer and topography effect that we can not solve with this method. So we try to use joint hypocenter determination methods including determining arrival time, travel time, hypocenter, station correction, and 1-D velocity model in simultaneous mode.

## METHOD

### Event Identification

Values of ts-tp can be used as reference to classify event, because it has correlation with distance between source and receiver. Correlation between ts-tp and distance between source and receiver can be explained from following equation 1 and 2.

$$t_p = \frac{D}{V_p} + t_o \qquad (1)$$

and

$$t_s = \frac{D}{V_s} + t_o \qquad (2)$$

We can make simply equation from that equations, where $t_o$ is origin time of earthquake and $V_p > V_s$; $t_p < t_s$.

$$t_s - t_p = D\left[\frac{V_p - V_s}{V_p V_s}\right] \qquad (3)$$

$$D = \left[\frac{V_p V_s}{V_p - V_s}\right](t_s - t_p) \qquad (4)$$

If we assume that average of Vp and Vs is 3038 m/s and 1756 m/s, we can use equation 2.4 can determine epicenter position. Table 1 show that approximation values of epicenter with different ts-tp values.

*Table 1: Table relation between epicenter positions with ts-tp values*

| ts-tp (s) | Distance (km) | Category |
|---|---|---|
| 1 | 4.161 | Local |
| 2 | 8.323 | Local |
| 3 | 12.484 | Local |
| 4 | 16.645 | Regional |
| 5 | 20.806 | Regional |
| 6 | 24.968 | Regional |
| 7 | 29.129 | Regional |
| 8 | 33.290 | Regional |
| 9 | 37.451 | Regional |
| 10 | 41.613 | Regional |

Microearthquake have higher frequency content than regional earthquake.

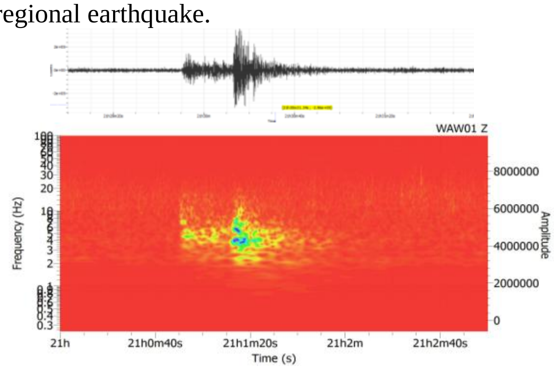



*Figure 1: A regional earthquake that has ts-tp more than 30 second has frequency content between 2-10 Hz.*

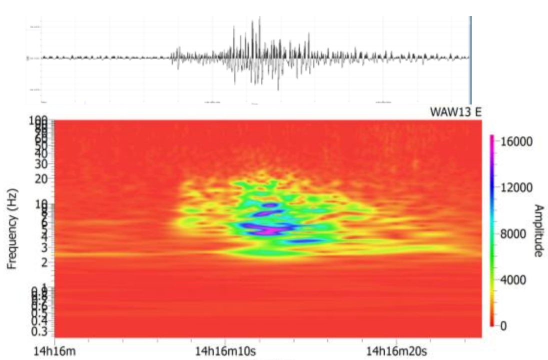



*Figure 2: A microearthquake that has ts-tp more than 3 second has frequency content between 2-30 Hz.*

## Geiger's Method

This method used arrival times of P and S waves, stations location, and 1D velocity model. The residual time is difference between observed and calculated arrival time.

$$r_i = t_{obs}^i - t_{cal}^i \tag{5}$$

$$r_i = \left(\frac{\partial t_i^{cal}}{\partial x_i}\right)\Delta x + \left(\frac{\partial t_i^{cal}}{\partial y_i}\right)\Delta y + \left(\frac{\partial t_i^{cal}}{\partial z_i}\right)\Delta z + \Delta t_0 \tag{6}$$

where:
$r_i$= travel time residual
$t_{obs}^i$= observation arrival times at station *i*
$t_{cal}^i$ = calculation arrival times at station *i*

In this study we used GAD software that is used Geiger's method with adaptive damping. If ordinary Geiger used $G^T d = G^T G m$, but in GAD used $G^T d = (G^T G + \lambda)m$, where $G = \frac{\partial t_i^{cal}}{\partial x_i}, \frac{\partial t_i^{cal}}{\partial y_i} \frac{\partial t_i^{cal}}{\partial z_i}$

## Joint hypocenter determination

In this case, the velocity model is used in 1D models, it aimed to do as simplification of subsurface models. 1D velocity model is used as a procedure to determine hypocenter and as an initial velocity model for seismic tomography (Kissling et al., 1994). One of method to determine 1D velocity model is coupled velocity-hypocenter method using VELEST program version 3.1 (04/10/95) (Kissling, 1995).

VELEST can be used to solve problems such as:

1. The coupled hypocenter-velocity model problem for local earthquakes, quarry blasts, and shots; for fixed velocity model and station corrections VELEST in simultaneous mode performs the Joint-Hypocenter-Determination (JHD).
2. The location problem for local earthquakes, blasts, and shots.

Coupled hypocenter-velocity method is a method of relocating earthquake, seismic wave velocity model determination subsurface 1D and correction stations simultaneously using the principle method of Geiger. The number of model parameters (m) is 5 + N, (x, y, z, $t_0$, station corrections, and N is the number of 1D velocity model layers). As a first step, the parameters are defined focal m0 (x, y, z, t0), seismic wave velocity model (1D) and station corrections. For the next step is doing ray tracing of earthquake to obtain Tcal (travel time calculation).

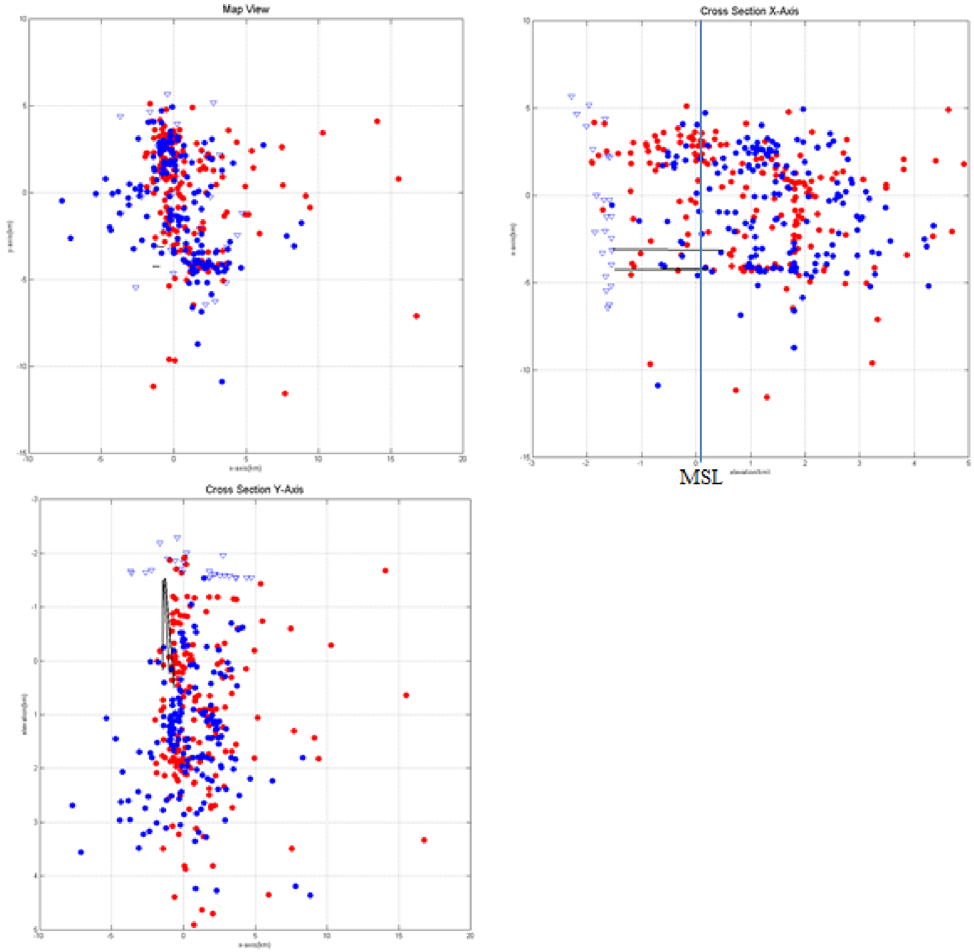



*Figure 3: Figure shows map view, vertical cross section along x-axis, vertical cross section along y-axis of microseismic hypocenter usingGeiger's method (red dot) and joint hypocenter determination metod (blue dot) with station reciever (blue trianlge) and black line (well)*

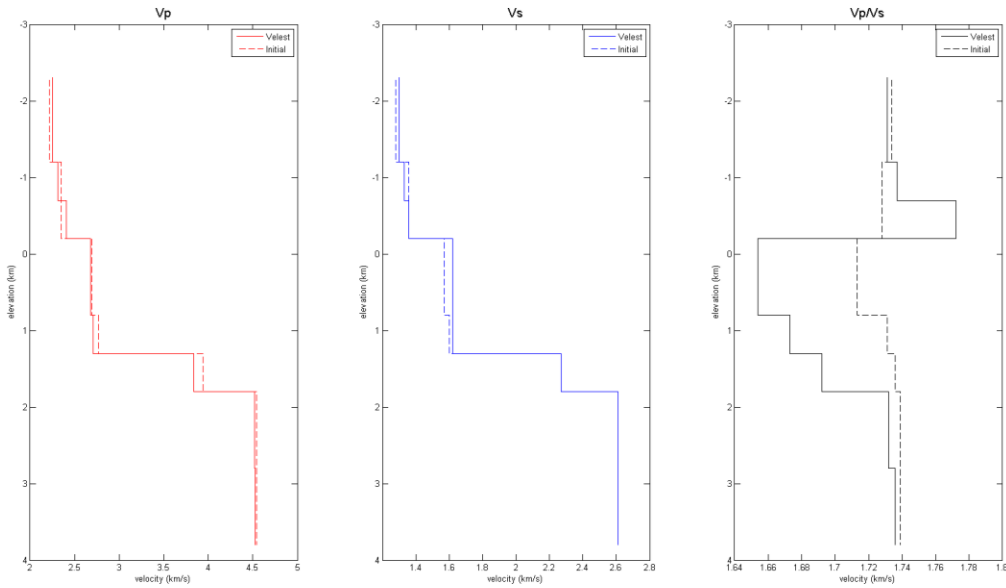
Inverse modeling can be used with completing damped Matrix Least Square [At A + L] (A = matrix Jacobi, Jacobi matrix At = Transpose; L = damping matrix). Using the value of damping will affect the value of the perturbation parameter model (Δm), the relationship between the magnitude of the damping and the value of Δm is the opposite.

Results of inverse modeling are vector of improved parameter model (Δm) which us consist of hypocenter, velocity model and station corrections. In the next step, it is used in forward modeling as input. In iteration there is RMS value between observation and calculation travel time, so iterations number can be set up to expected RMS.

## RESULTS AND DISCUSSION

From identification data we get 263 microearthquake that have ts-tp less than 3 second. But after we processed it with Geiger's method some of microearthquake is located below 5 below msl. To determine using joint hypocenterdetermination method, we only choose miroearthquake that is located in 5 km below msl.

Fromfigure 3, we can see the difference hypocenter locations between Geiger and Velest. Some of event that is calculated by Velest is clustered below injection well. Result from Velest is better than Geiger, if we compare from travel time residual from both of them (figure 4).

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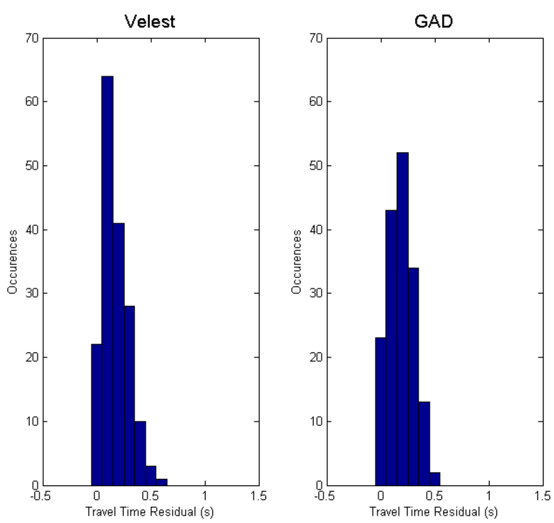


*Figure 4: A regional earthquake that has ts-tp more than 30 second have frequency content between 2-10 Hz.*

After we get hypocenter location, we calculate 1D velocity model, update hypocenter location, and stations correction. Vp/Vs from this step show that there is low anomaly in -0.2-08 km (figure 3). It can be indication of vapor reservoir. It can be happened because of low Vp and high Vs. Low Vp can be occurred because of high compressibility and high Vs can be occurred because of pore pressure reduction that make high shear modulus (Boitnott, 1997). Low station correction can be interpreted as solid material and high station correction can be interpreted as leather or non-solid material.

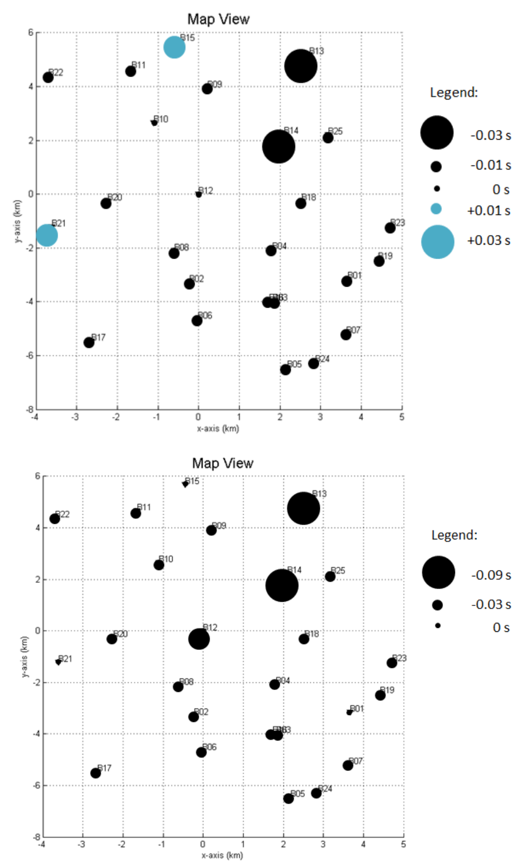


*Figure 4: Station distribution and station correction values of P-Waves and S-Waves*

*Table 2.Station Correction that is determine using VELEST*

| Station | X (km) | Y (km) | Z (km) | P-Wave | S-Wave |
|---|---|---|---|---|---|
| B01 | 3.67 | -3.15 | -1.541 | -0.01 | 0 |
| B02 | -0.22 | -3.28 | -1.719 | -0.01 | -0.02 |
| B03 | 1.83 | -3.96 | -1.547 | -0.01 | -0.02 |
| B04 | 1.81 | -2.05 | -1.672 | -0.01 | -0.02 |
| B05 | 2.18 | -6.45 | -1.62 | -0.01 | -0.02 |
| B06 | -0.02 | -4.63 | -1.66 | -0.01 | -0.02 |
| B07 | 3.64 | -5.19 | -1.562 | -0.01 | -0.02 |
| B08 | -0.59 | -2.11 | -1.861 | -0.01 | -0.02 |
| B09 | 0.22 | 3.96 | -2.01 | 0.01 | -0.03 |
| B10 | -1.11 | 2.67 | -1.904 | 0 | -0.04 |
| B11 | -1.64 | 4.68 | -2.192 | -0.01 | -0.04 |
| B12 | 0 | 0 | -1.828 | 0 | -0.05 |
| B13 | 2.73 | 5.19 | -1.957 | -0.03 | -0.09 |
| B14 | 2.11 | 2.25 | -1.616 | -0.03 | -0.09 |
| B15 | -0.45 | 5.68 | -2.288 | 0.02 | -0.01 |
| B16 | 1.74 | -3.96 | -1.553 | -0.01 | -0.02 |
| B17 | -2.64 | -5.46 | -1.654 | 0.02 | -0.01 |
| B18 | 2.53 | -0.25 | -1.59 | -0.01 | -0.02 |
| B19 | 4.41 | -2.43 | -1.554 | -0.01 | -0.02 |
| B20 | -2.23 | -0.24 | -1.689 | -0.01 | -0.02 |
| B21 | -3.61 | -1.21 | -1.636 | 0.02 | -0.01 |
| B22 | -3.69 | 4.4 | -1.667 | -0.01 | -0.04 |
| B23 | 4.72 | -1.18 | -1.555 | -0.01 | -0.02 |
| B24 | 2.87 | -6.25 | -1.587 | -0.01 | -0.02 |
| B25 | 3.19 | 2.21 | -1.579 | -0.01 | -0.02 |

## CONCLUTION

From From this study, we can conclude that:

1. Most of microearthquake have low difference arrival time of P and S waves and have higher frequency content than regional earthquake.
2. Hypocenter determination using Velest gives better result, if we see from clustering event and travel time residual.
3. Some of event that is clustered beneath well injection, may be occured because of injection activity.
4. 1D velocity model which is determined by velest has anomaly in -0.2-0.8 km below mean sea level can indicated as vapor reservoir.
5. With station correction we can interpreted material condition around station and based on

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