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To cite this article: Muhamad Firdaus Al Hakim *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **318** 012039

IOP Conf. Series: Earth and Environmental Science **318** (2019) 012039 doi:10.1088/1755-1315/318/1/012039

Seismicity Analysis and Velocity Structure of the Two-Phase Geothermal Field in West Java, Indonesia: Preliminary Result

Muhamad Firdaus Al Hakim[1], Rachmat Sule[2], Andri Hendriyana[2]

[1]Master Program of Geothermal Engineering, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung
[2] Exploration and Engineering Seismology Research Group, Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung

E-mail: firdausalhakim@gmail.com

Abstract. We observed 754 microearthquake data by at least 15 stations for six months as a tool to monitor and characterize the subsurface condition in two-phase geothermal field in Southern Bandung. The data were reduced to 417 events having azimuthal gap less than 180°. We determine the initial earthquake locations in this study by using Geiger method and we update the hypocenter locations by performing simultaneous inversion for hypocenters and 1D velocity structure followed by 3D tomographic inversion. We obtained the velocity structure by utilizing TomoDD to perform 3D tomographic inversion. There are four clusters of seismicity observed in this study which we suspected related to the injection, production, and tectonic activity of the study area. The southern cluster is consistent with the location of injection wells and spread from 1 km depth to 8 km depth, indicating that MEQ events were triggered by injection activity. The production area is characterized by a denser population of events and the events were distributed closely ranging from 1 to 3 km depth. We suspect that the third cluster is caused by development activity of steam dominated geothermal field omit in the east of our main field. The fourth cluster is located in the southernmost of our area and suspected caused by tectonic activity. Low Vp/Vs values near to the surface are observed in the north direction and coincide with the location of the first cluster. The location of anomaly is highly corresponded with the production area and the low value of Vp/Vs anomaly is interpreted as the steam zone.

1. Introduction

The micro-earthquake monitoring has been conducted in the two-phase geothermal field in Indonesia. Geothermal reservoir monitoring using MEQ is dedicated to describing subsurface condition such as permeability zone, reservoir boundaries, and the fluid saturation in reservoir. Geothermal development activities can trigger micro-earthquakes caused by interaction between cold condensate and hot reservoir rocks, declining pore pressure caused by fluid production from reservoir (Majer et al., 2007).

The micro-earthquake study in two-phase geothermal reservoir had been conducted by Delliansyah (2014), Muchlis (2015), and Akbar (2015) which showed the distribution of events are highly related to geothermal activities. The purpose of this research is to determine the location of micro-earthquake which is caused by geothermal development activities in two phase geothermal field and the imaging of 3-D velocity structures to delineate the reservoir boundary and estimation of steam and brine zone. Analysis was conducted by comparing the location and distribution of hypocenters to the location of

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wells and geological features in the area. We also conducted preliminary 3-D velocity structure inversion to estimate the steam-water contact and reservoir boundary.

2. Data and Method

15 seismometers were deployed in the study area, however only 13 stations have succeeded record the events. The arrival time information of P and S phase were picked manually from January 2016 to June 2016. We obtained 754 events with 4650 P phase and 4650 S-phase. Geiger's Adaptive Damping (GAD) (Nishi, 2005) was applied for the initial location and origin time determination. The initial 1-D velocity model was modified from Palgunadi (2016). We conducted a quality control of the picking process by plotting Wadati diagram. The research workflow included: 1) implementation of Geiger's Adaptive Damping (GAD) for initial location and origin time determination, 2) the update of 1-D velocity model (Vp and Vs) and hypocenter relocation using program code VELEST (Kissling et al., 1994), and (3) simultaneous inversion for the 3-D tomographic velocity structure (Vp, Vs, and Vp/Vs) and the hypocenter using the program code TomoDD (Zhang & Thurber, 2003)

The locations of hypocenters from GAD served as initial input for VELEST (Kissling et al., 1994). The program was applied to relocate the hypocenters and simultaneously determine the 1-D velocity model and the station corrections. The updated model and hypocenter locations were used as the input for the 3-D simultaneous inversion. We used Vp/Vs ratio of 1.71 (Figure 1) as initial value in the inversion which estimated from a modified Wadati diagram. We select the events with depth less than 6 km bsl and azimuthal gap angles less than 180° which located inside seismometer network. The input of double difference seismic tomography inversion was using 362 events (2049 P-wave and 2049 S-wave arrival time phases) after selection.

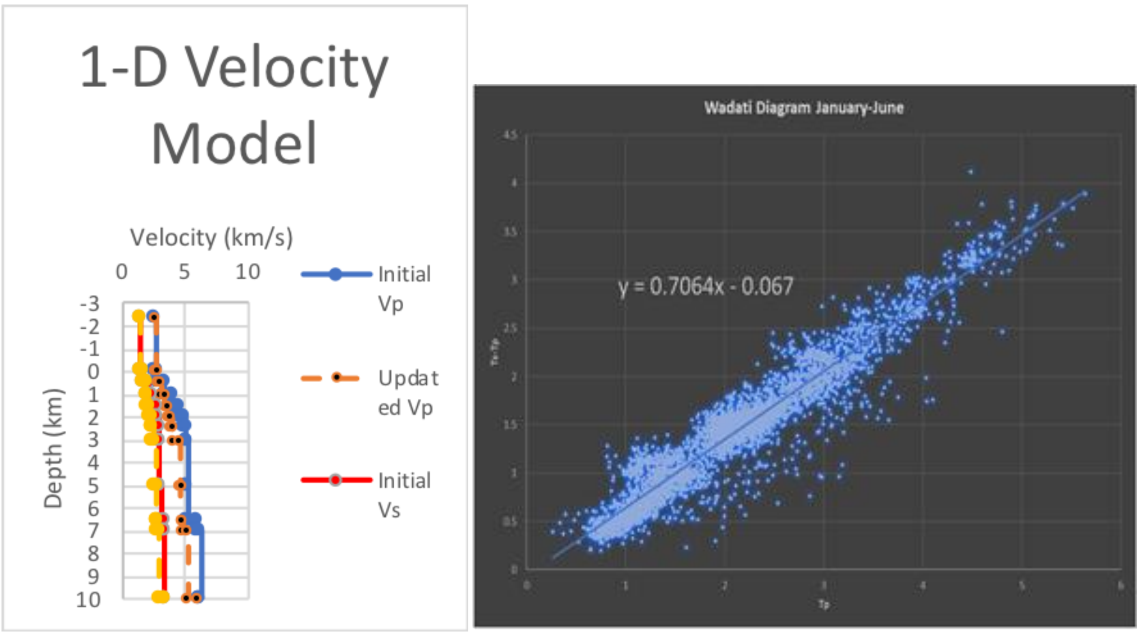

Figure 1. The 1-D velocity model derived from VELEST software inversion (left), Vp and Vs initial model (orange and green dash line) and updated velocity model (yellow and red solid line). Right figure shows Wadati diagram. Cyan circles stand for P-and S-wave travel time observation while solid line indicates regression curve. The value of Vp/Vs ratio is 1.7064.

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3. Result and discussion

There are four seismicity clusters observed after we applied *Joint Hypocenter Determination* (Figure 2) which we suspected related to the injection, production, and tectonic activity of the study area. The first cluster is located in the northern area and the events were distributed closely from 1 km to 3 km depth. The location of the first cluster is consistent with the location of production wells which may be triggered by production activities. The second cluster is located in the south of first cluster and consistent with the location of injection wells and spread from 1 km depth to 8 km depth. Event distributions of the second cluster were relatively sparse compared to the first cluster.

The third and fourth clusters were located outside our geothermal working area. The third cluster could be triggered by development activity of steam dominated field omit in the east of our main field. The fourth cluster is in the southernmost of the study area and unrelated to the geothermal activities. We suspected the fourth cluster was caused by tectonic activity as most of the events have depth more than 6 km bsl.

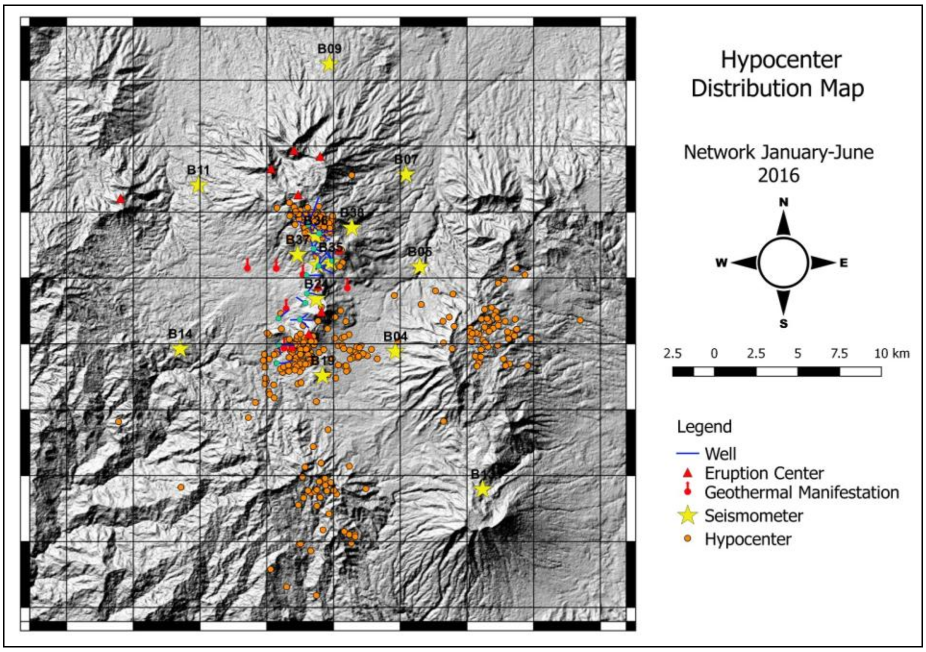

Figure 2. The map of hypocenter distribution of events after relocation using JHD. The orange dot represents the location of the events. The main field area of our field is located at the center of the map. The easternmost cluster is outside the two-phase geothermal working area and coincides with different geothermal working area.

Figure 3 shows the preliminary results of TomoDD inversion in vertical section for North-South direction of the study area. We plotted the value of Vp and Vs structures in percent perturbation relative to the initial seismic velocity models and ratio of Vp/Vs. We observed high lateral contrast between south anomaly zone and north anomaly zone. The high perturbation in the southern part may indicate the existence of dense body such as intrusion. The negative perturbation in the north could be related to the existence of geothermal fluids and indicate the reservoir zone. The lateral contrast of the positive and negative perturbation of Vp and Vs may indicate the boundary of the northern part. We observed the existence of low Vp/Vs ratio at elevation of 0.5 km to -0.5 km in the reservoir area. This low Vp/Vs ratio may be related to the existence of steam zone of this field.

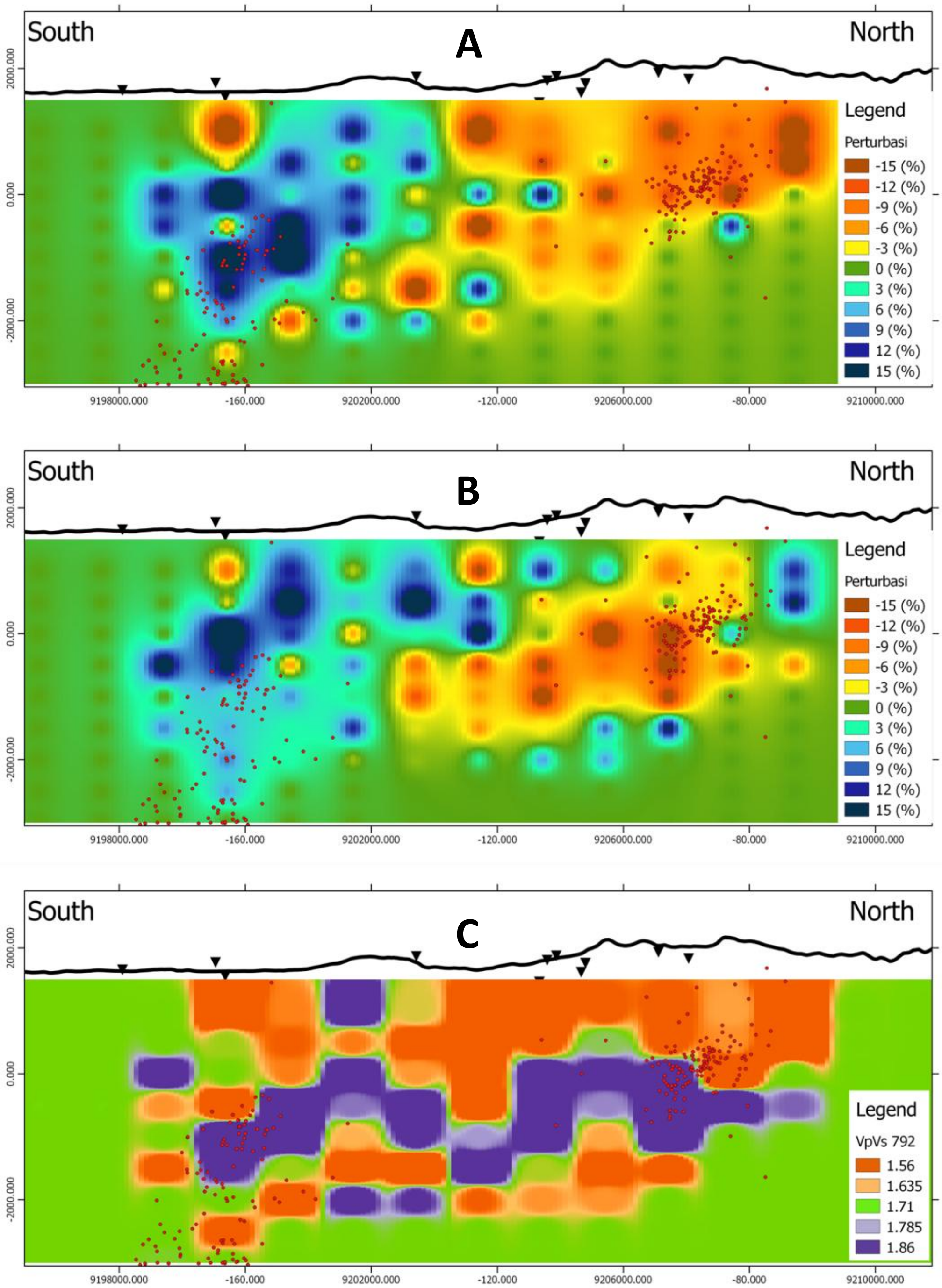

Figure 3. The vertical section for velocity structures of Vp (A), Vs (B), and Vp/Vs (C) in North-South direction. Blue color indicates high perturbation value and high Vp/Vs ratio. Orange colour indicates negative perturbation value of Vp and Vs. Red colour of C figure represent low Vp/Vs value. Red dots represent hypocenters distribution vertically. Black triangles are seismometers.

4. Conclusions

We observed four clusters based on relocation using JHD: Cluster 1 events were distributed closely ranging from 1 to 3 km depth in production area. Cluster 2 is consistent with the location of injection wells and spread from 1 km depth to 8 km depth, indicating that MEQ events were triggered by injection activity. Cluster 3 is caused by development activity of steam dominated geothermal field omit in the east of our main field. Cluster 4 is located in the southernmost of our area and suspected caused by tectonic activity

First inversion of 3-D velocity model shows that the location the low value of Vp/Vs anomaly is highly conform with the production area and interpreted as the steam zone. There is also lateral contrast of Vp and Vs in the south which can be interpreted as reservoir boundary of our geothermal field. We plan to apply smoothing and damping analysis to obtain best parameter for inversion.

Acknowledgments

We are grateful to Prof. Anthony Lomax for his software Seisgram2Kv.7.0 used in this study. Most maps were prepared using the QGis 2.18 Software. Topography data was taken from SRTM 30 Plus. Well locations were obtained from Kusumah et al (2010).

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