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TIME LAPSE (4-D) SEISMIC VELOCITY TOMOGRAPHY USING MICRO-SEISMIC DATA IN GEOTHERMAL FIELD

Ahmad Syahputra[1], Andri Dian Nugraha[1], Rachmat Sule[1]

[1]Geophysical Engineering, Institut Teknologi Bandung
Ganesha 10, Bandung - Indonesia
e-mail: ahmadsyahputra@live.com

ABSTRACT

Micro-seismic monitoring has become one of the primary methods for behavior of reservoir monitoring in geothermal field. Monitoring is conducted every time. In this study, we tried to observe the velocity changes as physical properties of reservoir within two different times. Those times are first time before the water injection phase in 2007 and second time after injection phase done in 2007-2008. We used these two different time periods of microearthquake data catalog to invert for seismic velocity cube structure by using tomographic method. Injection phase was initiated in second year. In this study, there are velocity changes from low velocity to high velocity after injection phase on injector wells area. It is caused by increasing bulk modulus of reservoir rocks that are initially dry or gas filled to be water saturated. It can be use to interpret the direction and delineation of fluid injected in reservoir. 4-D monitoring can be done by using the micro-seismic annually or any events such as injection phase, hydraulic fracture or etc. This study still continues to be developed to determine a few correction and tolerance must be treated due to imbalance in the number of data and tomography inversion is not produce the absolute value of velocity.

Keywords: Tomography, Monitoring, 4-D

INTRODUCTION

In this study, we tried to observe the velocity changes as physical properties of reservoir within two different times. Those times are first time before the water injection phase in 2007 and second time after injection phase done in 2007-2008. We used these two different time periods of microearthquake data catalog to invert for seismic velocity cube structure by using tomographic method. Injection phase was initiated in second year. Micro-earthquake hypocenters are normal scattered distribution (*Figure 1*). Later on after the injection phase begins, the hypocenters distribution formed several geological trends.

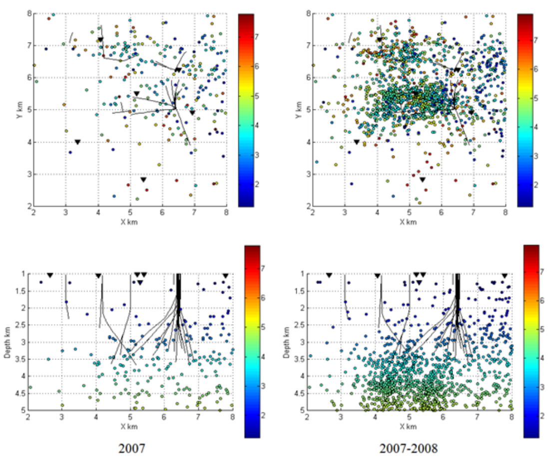

Figure 1: Figure shows map and cross-section West to East of wells trajectory (black line), stations distribution (black triangle), and MEQ hypocenters (color circle) distribution on 2007 (left) and 2007-2008 (right), respectively. More micro-earthquakes events were recorded in 2008 due to water injection into reservoir using some injector wells. Hypocenter colors scale show the depth of MEQ hypocenters from datum (+2km above sea level).

METHODOLOGY

First Arrival Time Tomography

The travel time of seismic wave (T) from source i to receiver j can be expressed using ray tracing as integral,

$$T_{ij} = \int_{source}^{receiver} u_{(x,y)}\, ds \tag{1}$$

where $u_{(x,y)}$ is slowness (reciprocal of velocity) and ds is segment length of ray.

Travel time is calculated from difference between first arrival time of micro-earthquake event with the origin time. In forward modeling, travel time between source and receiver is calculated by using pseudo bending ray-tracing (Um & Thurber, 1987). Pseudo bending is an approach in minimization of travel time base on Fermat's Principle by giving small perturbations gradually on ray paths. Delay time tomography is used to solving non-linier inversion problem iteratively (Nolet & Guust, 1987; Widiyantoro et al., 2000; Nugraha & Mori, 2006). For inversion, LSQR method (Paige & Saunders, 1982) is implemented in order to update subsurface seismic velocity model for each iteration. Norm and gradient damping are added to constrain blocks without ray and to produce smooth solution model, respectively (Grandis, 2009; Widiyantoro et al., 2000).

4-D Tomography

4-D or time lapse tomography has a simple principle. The 4-D principle is assuming velocity as physical property of reservoir as a time function. Observation was made 3-D seismic velocity from a different time. Changes of 3-D velocity can be expressed in an equation,

$$\Delta V = V_{t2} - V_{t1} \tag{2}$$

where ΔV is seismic velocity difference and V_{ti} is seismic velocity as time function.

In this study, we use the similar parameters for each tomography inversion in different time. The inversion parameters are number of iterations, norm, and gradient damping. There was no special correction in this tomography inversion.

RESULT & DISCUSSION

This study focus on around injector wells area and the reservoir depth interval at of 3-4.5 km from datum. Model parameterization is used heterogeneous dimension blocks. Checkerboard Resolution Test (CRT) with ± 10 % pertubation relative to initial velocity was conducted to evaluate the model resolution of the tomography inversion. To simplify the interpretation, we have done down-scaling of model parameterization to 10% smaller using cube interpolation method.

In this study, tomography inversion results are not plotted in the absolute values. Besides that, the issue is different numbers of micro-earthquake events every year. It can cause ambiguities of 4-D tomography observation. One way to reduce the ambiguities, we use a tolerance value. In this study, we use the tolerance value is ± 0.1 km/s, if the velocity changes is less than the tolerance value, the change can be ignored (white color).

CONCLUSIONS

In this study, there are velocity changes from low velocity to high velocity after injection phase on injector wells area. There are caused by increasing of bulk modulus because the initial reservoir is dry or contains gas replaced by water. It can be used to interpret the direction and delineation of fluid injected in reservoir. This study still continues to be developed to determine a few correction and tolerance must be treated due to imbalance in the number of data and tomography inversion is not produce the absolute value of velocity.

ACKNOWLEDGEMENT

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Depth-section 3.0 km

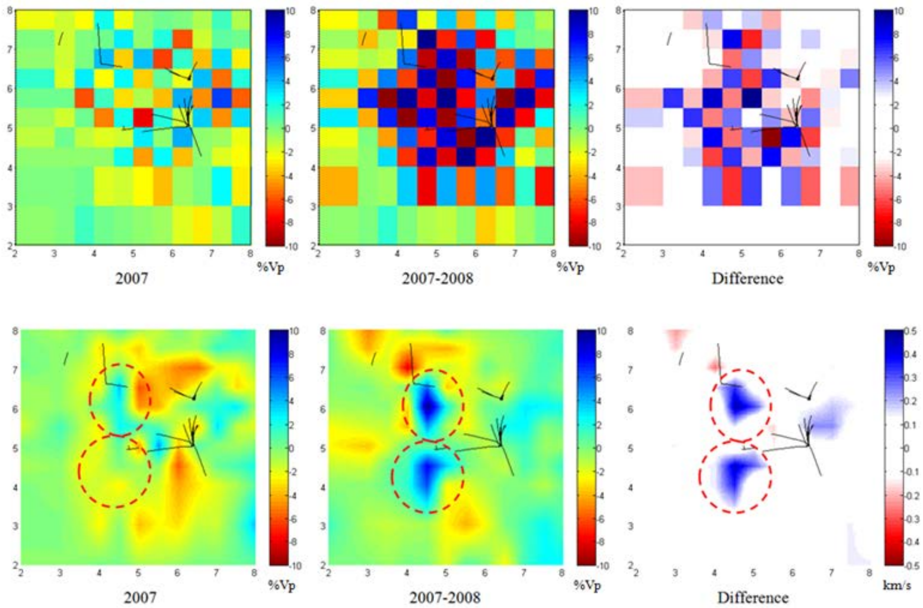

Figure 2: Map of checkerboard resolution test (top) and tomogram perturbation Vp (bottom) at depth of 3.0 km from datum. Checkerboard resolution test result of 2007-2008 showed a better resolution than 2007. Areas of interest (red dash line) show a velocity change from low (warm color) to high velocity anomaly (cool color). In tomogram of checkerboard resolution test has a big value difference, but they are the same pattern of CRT on area of interest. The tomogram difference of Vp show strong changes up to 0.5 km/s on injection area. Probably, this is an effect of fluid that has been injected into the reservoir.

Cross-section W-E 5 km

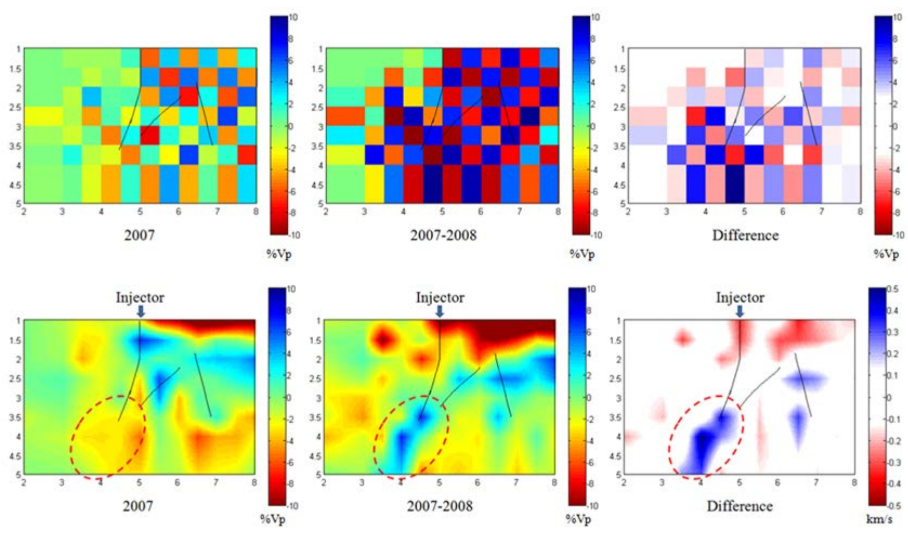

Figure 3: Cross-section of checkerboard resolution test (top) and tomogram Vp (bottom) from west to east at 5 km. Checkerboard resolution test result of 2007-2008 showed a better resolution than 2007. Area of interest is a reservoir interval. Areas of interest (red dash line) show a velocity change from low (warm color) to high velocity anomaly (cool color). In tomogram of checkerboard resolution test has a big value difference, but they are the same pattern of CRT on area of interest. The tomogram difference of Vp show strong changes up to 0.5 km/s on injection area. Probably, this is an effect of fluid that has been injected into the reservoir. This high velocity anomaly patterns tend to bottom due to the effect of gravity working on fluid injection. On surface (depth of 1-1.5 km from datum), velocity change to low velocity (warm color) possibility due to surface change such as the entry meteoric water or sediment loading on the surface.