PROCEEDINGS, 13th Indonesia International GEOTHERMAL Convention & Exhibition 2013
Assembly Hall - Jakarta Convention Center Indonesia, June 12 – 14, 2013

IDENTIFICATION OF FLUID ZONE USING VP/VS RATIO STRUCTURE DERIVED FROM MICRO-SEISMIC TOMOGRAPHY IN GEOTHERMAL EXPLORATION

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ABSTRACT

Micro-seismic events are routinely observed due to hydraulic fracturing, fluid injection, and signature normal earthquakes from local fault activities during geothermal exploration. A micro-seismic event generates and propagates seismic waves (P-and S-waves) through the medium beneath subsurface recorded by receivers on the surface or in a borehole (seismograph or geophone). Vp/Vs ratio is one of physical properties that can be used to determine fluid-filled rock zone. In this study, we used data catalog of micro-seismic events including P-and S-wave arrival times, origin times, source and receiver locations to invert for seismic velocities structure especially for Vp/Vs ratio structure using tomographic inversion method in a geothermal field. Our tomographic inversion results show a prominent feature of high Vp/Vs ratio a depth of about 0.25 km to 1.25 km (beneath the Mean Sea level) around injection wells. This high Vp/Vs value coincides with low Vp and low Vs values as indication of high pore fluid pressure. Our interpretation is that high Vp/Vs with low Vp, and low Vs may be related to fluid-filled rock zone from the injection well. From this study, we can show that seismic tomography inversion represents one of powerful methods to delineate the subsurface structure, especially for reservoir characterization.

INTRODUCTION

Fluid stimulation injections are often used for the development of geothermal exploration. The induce micro-seismic caused by stimulation injections have been generally well known for geothermal and hydrocarbon exploration (Shapiro, 2008). Micro-seismic monitoring of fluid injections is one of tool to enhance our understanding of fluid-filled rock properties and also to characterize of geothermal reservoir. A large number of micro-seismic events recorded by good seismometer distribution can be used for 3-D seismic velocities subsurface imaging. Variation in seismic velocities (Vp, Vs, and Vp/Vs ratio) depend on rock properties such as porosity, permeability, fracture, pressure, fluid saturation, and lithification. Delineation of Vp/Vs ratio structure can be a useful tool both in the exploration as well as for monitoring during exploitation of a geothermal reservoir (Huenges, 2011). In this study, we conducted travel time tomography inversion to determine seismic velocities especially Vp/Vs ratio using micro-seismic data catalog.

DATA AND METHODOLOGY

In the present study, in order to investigate and understand physical properties beneath geothermal exploration field, we conducted seismic tomography inversion by applying SIMULPS12 method which provides a simultaneously inversion for both hypocenter and the 3-D Vp and Vp/Vs structure (Evan et al., 1994). The goal of this method is to improve the estimates of the model parameters (velocity structure and hypocenters) by perturbing them in order to minimize the weighted root-mean-square (RMS) misfit. In this method, P arrival times and S-P times are inverted for earthquake location, Vp, and Vp/Vs ration structures. The model resolution and covariance matrices (Menke, 1989) can be calculated directly because the full matrix inversion is carried out as shown in Figure 1.

The data were P and S arrival times provided by Chevron Geothermal Salak for January 2007 to January 2010. We used 2,909 micro-seismic events with 15,310 P and 12,704 S arrival times from 23 stations in this study area. For the spatial resolution we set up horizontal spacing of 1 by $1km^2$ and average 1 km in the vertical direction. The micro-seismic events have magnitude less than M2 and are too small to be felt at the surface and there have been no events large enough to cause any surface disturbance or damage (Stimac et al., 2008; Wibowo et al., 2010). More details information about micro-seismic events data used in this study are described in previous study of Stimac et al. (2008) and Wibowo et al. (2010).

RESULTS AND DISCUSSION

The results for Vp/Vs structure and Diagonal Resolution Element (DRE) beneath geothermal field at depth of 1,25 km below mean sea level are shown in Figure 1. There are high Vp/Vs regions around the injection well of 9, 14, 15, 17, and 18. Meanwhile, low Vp/Vs regions are observed around production well of 1. Seismic velocities changes can vary in geothermal area, where stronger drop of Vp/Vs and high P-wave attenuation are expected when the volume of steam is high (Huenges, 2011). The high Vp/Vs ratio can be found when stimulation or hydraulic fracturing of liquid-filled rock is intense will lead to drop of Vs and minor reduction in Vp. From laboratory of Christensen (1984), high Vp/Vs correspond to high Poisson's Ratio means over pressure or high pore-fluid pressure.

CONCLUSIONS

We conducted micro-sesmic tomography to invert for seismic velocities structure especially Vp/Vs ratio structure in geothermal exploration. We observed high Vp/Vs ratio structure around injection wells and low Vp/Vs ratio structure around production well. Our interpretation is the high Vp/Vs ratio around the injection wells may correspond to high pore-fluid or liquid-filled rock, whereas low Vp/Vs around production well may be associated with the steam zone. From this study, we can show that seismic tomography inversion represents one of powerful methods to delineate the subsurface structure, especially for reservoir characterization.

ACKNOWLEDGEMENTS

We gratefully acknowledge the use of micro-seismic data Catalog from Chevron Geothermal Salak.

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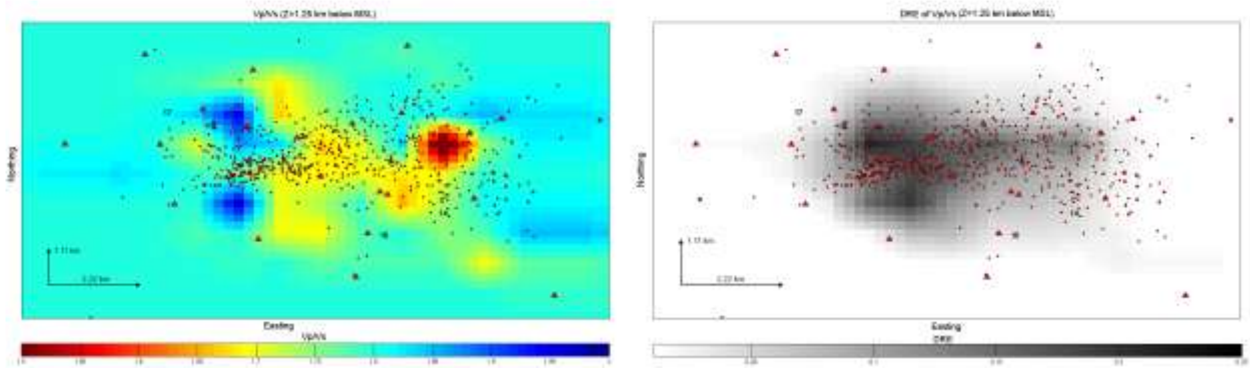

Figure 1: (left) Vp/Vs structure at depth of 1.25 km beneath MSL is plotted as absolute value. Blue and red colors indicate high and low Vp/Vs ratio value, respective. (right) The results of the diagonal resolution element (DRE) test ranging from 0.01 – 0.25 (resolved). High DRE value can be supported for valid interpretation. Red circles and red triangles stand for epicenter of micro-seismic events and seismometer location, resepectively. The injections wells head location are shown by number of 9, 14, 15, 17, and 18. While production well head location is indictaed by number of 1.