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SEISMIC ATTENUATION TOMOGRAPHY USING MICROEARTHQUAKE DATA IN THE "M" GEOTHERMAL FIELD

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ABSTRACT

Attenuation is the physical parameters of rock that can reflect the subsurface geological conditions. We conducted attenuation tomographic imaging in the geothermal field by using the Microearthquake (MEQ) data in the form of attenuation operator, t*. We applied a method of spectral fitting to invert for the t* value. For the attenuation tomographic inversion, we used the initial 3-D velocity model from the previous study in the region. Our study results show that the value of Qp, Qs and Qp/Qs ratio in the geothermal field is an important parameter for interpreting the subsurface structure. The geothermal field in this study lies between several active and dormant volcanoes in west Java Province, Indonesia. This geothermal field already produces electricity of more than 220 MWe. The hydraulic stimulation has been carried out from the end of 2007 until the beginning of 2008 in order to get an understanding about the orientation of weak or fractures zones, so that the strategy of exploration and well targeting could be estimated. We interpreted the combination results of Qp, Qs and Qp/Qs ratio structures with previous seismic velocities (Vp, Vs and Vp/Vs ratio). We can see that the high attenuation value (low Q value) and low velocity anomaly structures may be corresponded to fluid-filled rock and also fault segment.

INTODUCTION

Microearthquake (MEQ) method is one of geophysical method that used both in exploration and monitoring in geothermal field. This study using MEQ data applied for expansion production area. Microearthquake monitoring method performed during the injection fluid. This process use for making hydraulic fracture and also to identify subsurface permeability and fracture the formation of a new direction based on microearthquake event. This process have done three times (on 1998, 2005, 2007) in this geothermal field. This study used data at 2007 injection, monitoring have been done for 44 days and obtained selected 163 events with high quality of signal and have t* more than 6. These data use for determining subsurface geological structure with seismic attenuation tomographic imaging method in this study.

Attenuation is the physical parameters of rock that can reflect the geological conditions beneath the surface. Seismic attenuation quantity express in Q, factor quality of seismic wave. Q indicates the capability of medium to transmit the energy. Variation value of attenuation can be caused by the impedance contrast, chemical composition, structural faults, and variations in temperature on the brittle seismogenic crust. In the study conducted in the California region using data seismicity as a resulted in significant variations are interpreted as the Q value of the heterogeneity of the temperature distribution of the earth's crust (Schlotterbeck and Abers, 2001). This study use seismic attenuation imaging to determine geological structure includes fault, permeability zone, and also fluid contain at shallow subsurface.

Attenuation imaging use Q inversion and attenuation operator, t*, is needed. This operator we can get by using spectra fitting procedure. Three parameters need to be determined this procedure including corner frequency, fc, spectra level, Ω_0 and attenuation operator, t*. In this study we use velocity model 3D from previous research and use vertical component for P wave and also S wave waveform independent each other.

Attenuation values will have a high value in areas that have high permeability and contain fluid. In this study, we joint use of velocity and attenuation models that shown the subsurface condition. Velocity and attenuation images reveal different volumes of high pore pressure on fluid filled cracks.

DATA AND METHOD

The Microearthquake (MEQ) or passive seismic survey was carried out from December 2nd, 2007 to

January 13th, 2008 at geothermal field. That was recorded by 24-bit portable seismic recorders equipped with 3DLite Lennartz 1 Hz seismometers. 237 event was recorded and coverage by 10 station.
Only 126 events can resolved by TomoDD to get a velocity model 3D and 89 events for Qp tomography attenuation and 74 events for Qs tomography attenuation in this research we use vertical component of MEQ records. Another parameter that we need beside velocity model is attenuation parameter. We determine from each waveform.

Determining Attenuation Operator

We analyses microearthquake waveforms to determine t* values which are then used in the inversion for 3-D attenuation structure. The measurable parameter t* accounts for the whole path attenuation term in the amplitude decay (Eberhart-Phillips and Chadwick, 2002). t* value can formulated with :

$$t^* = t^*_{ij} + t^*_{station} \quad (1)$$

Where t^*_{ij} is the whole path attenuation and $t^*_{station}$ describes local site effect.
We use spectral fitting method to determine operator attenuation with the following expression from (Eberhart-Phillips and Chadwick, 2002) for source model assuming whole path attenuation. The velocity amplitude spectra:

$$A_{ij}(f) = 2\pi f \Omega_0 \frac{f_c^2}{(f_c^2 + f^2)} e^{-\pi f \left(t^*_{ij} + t^*_{station}\right)} \quad (2)$$

For each waveform, both Ω_0 and f_c value are determined along with t*. Ω_0 includes geometrical spreading of waveform. We conducted for spectra fitting procedure in wide range 2-20 Hz to determine common frequency, fc, for the event. The same event will have the same fc. In this study we use assumption Q-frequency independent tomography. And determining fc and low spectral have to be calculated carefully. We calculated velocity amplitude spectra for 0.4 s time windows, this length is the optimize value for this data. The data has arrival times difference between S wave and P wave (ts-tp) value 0.3–2.4s and for microearthquake event those time windows is long enough. A fast Fourier transform was applied to obtain the velocity amplitude spectra.

Q Tomography Inversion

The t* values are related to both Q and the velocity structure through; in general we can formulated seismic attenuation tomography inversion:

$$t^* = \int_{ij} 1/\left(Q_{(x,y,z)} v_{(x,y,z)}\right) ds + t^*_{stasion} \quad (3)$$

where ds is distance along the ray path from hypocenter i to station j and v(x, y, z) is the 3-D velocity model (Hauksson and Shearer, 2006). We applied SIMULP2000 by Thurber in 1993, Eberhart-Phillips (1993) and Thurder (1999) to perform the frequency independent Qp and Qs at 3-D grid nodes velocity structure. We use that velocity structure from previous research (Ramadhan, 2013), using TomoDD.
The initial Qp model we use 200, based on previous result (Suantika et al., 2008) research near field study. This value will be update during inversion to get the optimum result.

Quality of Inversion

In this study, resolution test such as checker board test was not conducted, so another parameter for verified quality of seismic attenuation tomography inversion was needed. Seismic attenuation tomography is evaluated by using three different methods. The errors in the final 3-D Q models are caused by errors in the t* determinations, inaccurate starting models, and errors related to the velocity models, such as incomplete parameterization and lack of resolution within certain parts of the model. We have calculated the resolution matrix, the derivative weighted sum, and the standard error to evaluate effects of data errors, and uneven ray coverage (Hauksson and Shearer, 2006).

RESULT AND DISCUSSION

In this study we use microearthquake data; this data recorded less than 4 km of depth. The result for attenuation operator, t*, value in ranges 0.0010 – 0.0294 for P wave and 0.0010 – 0.198 for S wave and we find that frequency corner value around 2-5 Hz and Ω_0 ranges value 2-15680 (fig. 1).
Base on result of quality seismic attenuation tomography successfully resolves to a depth of 3 km (1 km below sea level). The range value of Qp and Qs value at coverage area is around 165-250. This value varies at each depth and coverage area of this tomography decrease gradually by depth.
We can see join the result from velocity and attenuation tomography at fig 2. Velocity and attenuation of P-waves and S-waves in the upper crust depends on several factors including mineralogy, pressure, temperature, porosity and pore type, degree of rock fracturing, fluid saturation and pressure.

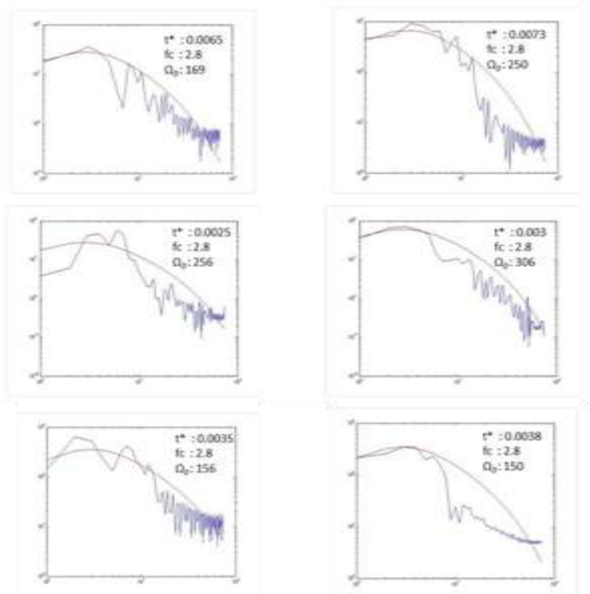

*Figure 1: Spectral fitting results for the P wave event recorded by six different stations (blue line for the data observations and the red line to the curve fitting), with t * values ranged between 0.0025-0.0065 with a corner frequency values ranged between 2.8 and Ω_0 150 -300.*

The joint use of the velocity and attenuation models allows us to infer more reliably the presence of fluids on the fault system. Moreover the presence of microearthquake event also suggest to fluid presence.
Based on the results of the inversion tomogram velocity and attenuation models, sectional horizontal and vertical cross-section can be seen that there are some segments of the fault in the north and west of the injection well.). Fault segment can be seen from the results of the value of Vp / Vs and Qp / Qs low. These fault segment presences surround well injection. The presence of fluid at a depth of 2-3km can be seen from inversion results of velocity and attenuation models Vp / Vs high, low Qp and Qp / Qs low (Chiarabba et al., 2009). Moreover Qp value is smaller than the value of Qp Qs 10-25% of the value of Qs shows the presence of rocks containing saturated fluid (Hauksson and Shearer, 2006). In addition based on seismicity patterns formed at depths of 2-3 km formed cracks, it can indicate that can be seen from inversion results of velocity and attenuation models Vp / Vs high, low Qp and Qp / Qs low (Chiarabba et al., 2009).
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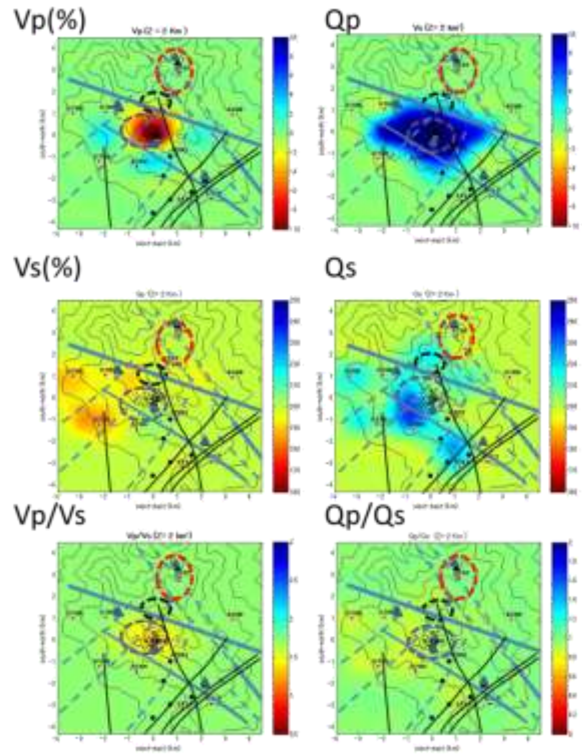

Figure 2: Left side panel show seismic velocity structure for Vp, Vs, and Vp/Vs ratio from previous study. Right side panel show attenuation structure for Qp, Qs, and Qp/Qs ratio and fault lines (black lines) at the depths of 2 km. Grey line is coverage area (good resolution); red dots is receiver station; tiny black dots is hypocenter MEQ event; black dots is production well; blue dot is injection well; blue triangle is volcanic mountain; blue line is geological structure. Blue and red colors indicate high and low value for Vp, Vs, Vp/Vs ratio, Qp, Qs, and Qp/Qs ratio respectively.

From that result we can see that attenuation tomographic can suggested to presence of fault segment and also fluid filled rock. In this geothermal area, we can see there is some fluid filled rock near injection well and also some crack and fault segment so this area has possibility to be production area later

CONCLUSSION

Seismic attenuation tomography can applied at geothermal area, it show a good variation of attenuation although in shallow subsurface. In geothermal field, attenuation value quite high it can be seen from t* value around value in range 0.0010 – 0.0294 for P wave and 0.0010 – 0.198 for S wave. In this study we can also see some fault segment can be seen from the results of the value of Vp / Vs and Qp / Qs low. Moreover we can see the presence of fluid that can be seen from inversion results of velocity and attenuation models Vp / Vs high, low Qp and Qp / Qs low.

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