Full-waveform Inversion (FWI) approach to the imaging of geothermal reservoirs

*Junzo Kasahara[1,2], Yoko HasaHa[3,2], Haruyasu Kuzume[2]

1. University of Shizuoka, 2. ENAA (Engineering Advancement Association of Japan), 3. Daiwa Exploration and Consulting Co. Ltd.

Introduction

In the geothermal development, seismic approaches have not frequently used. There are several reasons for this. The first reason might be the cost for doing seismic reflection survey in the geothermal field. The cost of seismic survey is thought to be more expensive than the EM and/or gravity surveys. In the oil exploration, costs for surveys are less important because the profits by oil and gas are huge. The second reason is probably difficulty to find the geothermal reservoirs due to complex geological circumstances and weak reflection signals. Usually oil/gas reservoirs tend to have large impedance contrast to the surrounding layers. Our approach is to use the temporal change of physical properties and location of reservoirs. By use of temporal change, large seismic property changes could be generated. We assume to use stable seismic sources enabling us to do long duration stacking enhancing S/N and full-waveform inversion method. In this study, we show the result of simulations using full-waveform inversion.

FWI imaging of geothermal reservoirs

To estimate the physical properties at the geothermal reservoirs, we applied the full-waveform inversion (FWI). Among many FWI methods we used adjoint approach developed by Tromp *et al* (2005). In the survey, we propose to use fiber optical distributed acoustic sensor (DAS) receivers along the borehole. We carried out three simulations: 1) a seismic active source(s) placed in the borehole and supercritical water reservoir at the 4km depth, 2) more realistic field study model and 3) natural earthquakes surrounding an igneous intrusion. In the first case, we used a geothermal reservoir model at the 4 km depth. We examined three source locations at 2km buried source depth. In the second case, we used a case of more realistic seismic observation system. We used a single force, surface seismometers and DAS in the borehole. In the third case, we assume an igneous intrusion with the top at the 4km depth. We tested nine natural earthquakes surrounding the igneous intrusion.

Result

First case: The reconstructed images assuming three source locations of 5 km, 3 km and 1 km from the drilling borehole show satisfactory retrieval of the assumed zone. The 3 km location case gave the best results. The Vp, Vs and density were retrieved as nearly the assumed model at the almost exact location and thickness.

The second case: We used two steps for inversion. By the first step, we estimated location of assumed reservoir model and retrieved appropriated shape and location of the model. Using this result, we calculated physical properties of the model. The result showed that Vp is partly estimated but the Vs is poorly retrieved.

The third case: The surface of igneous intrusion was imaged for Vs, but the smearing of intrusion was identified for Vp and density. Recovery of physical properties inside of the intrusion are not satisfactory.

Discussion and Conclusions

The result of FWI strongly depends on location and energy of the seismic source(s) and the location of seismic observation system(s). The aperture of seismic system is important. When we consider any realistic study field, good aperture coverage is difficult to be satisfied. The poor aperture might lose the FWI performance. Compared to the controlled seismic sources, natural earthquakes are difficult to choose the locations and size. Although controlled sources are mostly less energy, we can enhance the power of seismic waves by long duration stacking.

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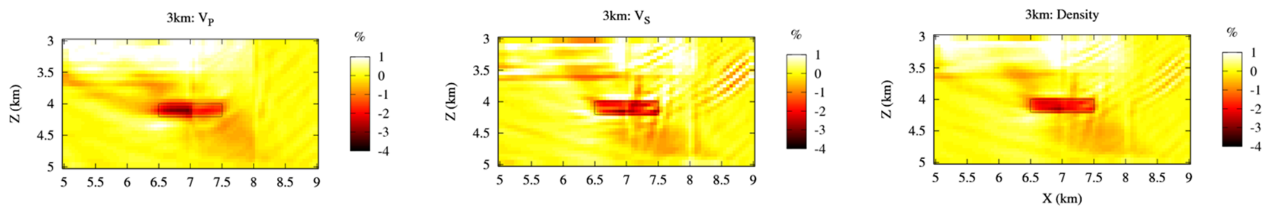

Figure : Simulation result of FWI model-1 for the source location at the 3 km distance from the drilling borehole. Left to right are Vp, Vs and density.