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4D seismic monitoring of the geologic sequestration of carbon dioxide

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To mitigate the global climate change due to excess carbon dioxide emission, geologic sequestration by carbon dioxide injection in the subsurface is proposed. To monitor and verify the long-term safe storage in the subsurface, 4D seismic technology is the most effective to spatially and efficiently detect the change of fluid saturation and pore pressure in the target aquifer and others. By RITE/METI Nagaoka project carbon dioxide was injected totally amounting to 10,405.2 CO2 tonnes during the period of July 2003 through January 2005. We conducted 4D seismic survey to monitor injected carbon dioxide in collaboration with RITE/METI. 3D seismic surveys were conducted in the area of 2x2km surrounding an injection and three monitor wells. It was the first 4D seismic survey for onshore aquifer injection monitoring in the world.

Target reservoir in saline aquifer is at approximately 1100m deep. Time-lapse wireline logging surveys were conducted at approximately one-month interval, which observed carbon dioxide break-through on two monitor wells with approximately 6m thick, but no indication on the well OB-3. To estimate the saturation zone by 3D seismic surveys, I had to overcome the problems 1) irregular 3D geometry in the land 3D seismic surveys, 2) to enhance data resolution to meet the thinner target reservoir, and 3) to estimate physical parameters.

In order to detect and highlight 4D anomaly zones, there are several methods. For relatively high noise content data, it is not a good method to simply subtract baseline and monitor seismic data since remnant non-repeatable noises influence the subtracted data. There are no ways to discriminate the noises from geological changes by this volume alone. Residual noises appear inevitable even after cross-equalization processing in onshore 3D surveys. 4D anomaly detectability is likely to be improved if supervised pattern recognition technology is implemented in the multi-attributes approach. 4D anomaly points are carefully selected on the 3D volume, and then the neural network is trained to identify 4D anomaly for a given binary set of anomaly and ordinary points with validation executed by smaller sets of points. As carbon dioxide was detected in the monitor wireline surveys on two wells, it would be probable that carbon dioxide exists on the lines connecting the injection well and the two monitor wells located on one line. Points connecting the injection well IW-1 and monitor wells OB-2 and OB-4 were selected as possible anomaly points for training. Estimated anomaly pattern is consistent with the observation of time-lapse wireline data and total amount of injected carbon dioxide. Pattern recognition technique applied to the multi-attribute set is to reduce data redundancy and remnant non-repeatable noises inherent to the onshore 4D seismic survey. It has improved the results of visual inspection of simple math difference of 3D seismic volume.

Waveform variations were taken as an indicator of velocity changes since the estimate of time-delay of the thinner single carbon dioxide saturated reflector with 15 deg dip was difficult to do. Amplitudes are the indicator of the thickness of thinner layers under tuning relationship. Exact thickness estimates are difficult, but the thinner layer location can be identified regardless of source frequency. 3D data were evaluated by well synthetics and impedance inversion to estimate several physical parameters such as porosity and permeability combined with the wireline data and geological constraints. Estimated high permeability by baseline data prior to the repeat survey showed a correlation with the detected 4D anomalies.

The first onshore 4D seismic monitoring of the injected carbon dioxide in aquifer was successfully conducted, though there were difficulties caused by the irregular 3D geometry and thinner target reservoir. It provides the prototype approach to the similar onshore carbon dioxide monitoring.