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Time-lapse offset and zero-offset VSP-data processing and imaging for monitoring CO_2 injection

Julia Götz (1), Stefan Lüth (1), Charlotte Krawczyk (2), and Calin Cosma (3)

(1) GFZ German Research Centre for Geosciences, Potsdam, Germany, (2) LIAG Leibniz Institute for Applied Geophysics, Hanover, Germany, (3) Vibrometric, Perttula, Finland

As part of the seismic monitoring at the Ketzin CO_2 storage site, time-lapse VSP data were acquired. The purpose of the VSP experiment was to complement 3D surface seismic data with higher spatial resolution in close vicinity to the injection well.
More than 45 kt of CO_2 were injected between the baseline and repeat VSP surveys. For each VSP survey, data were measured at one zero-offset and seven offset source locations around the injection site with offsets varying between 282 m and 907 m. The VSP was recorded in a vertical well using an 80 level 3C geophone string extending 325 – 720 m below ground level, with an interval of 5 m between the levels. The CO_2 was injected into a saline sandstone reservoir in 630 – 650 m depth. The injection well has a distance of 112 m to the recording well.
Processing and interpretation of the offset VSP data comprises the following steps: (1) Seismic elastic FD modelling based on well log data. (2) Time-lapse processing of the modelled and measured data (application of a shaping filter on the repeat data to match the traces of the baseline data, removal of downgoing waves by fk-filtering). (3) Imaging of the data with 2D Kirchhoff and 2D Fresnel migration. (4) Comparison of the VSP with 3D surface seismic data.
Processing and interpretation of the zero-offset VSP comprises the following steps: (1) Seismic elastic FD modelling based on well log data and results of the band limited impedance inversion. (2) Processing of the modelled and measured data (removal of downgoing and enhancement of upgoing waves by median filtering, application of an outside corridor to account for propagation effects of upgoing waves, such as multiples). (3) Band limited impedance inversion of the measured, modelled and 3D surface seismic data. (4) Comparison of the VSP with 3D surface seismic data.
The offset VSP is comparable to the 3D surface seismic for both imaging methods, the 2D Kirchhoff and the 2D Fresnel migration. The time-lapse data show the CO_2 signature in the depth range of the reservoir for those imaging planes crossing the CO_2 plume. The zero-offset VSP time-lapse data show strong amplitudes in the depth range of the reservoir caused by the injection of CO_2. The time-lapse amplitude of the modelled data is weaker than that of the measured data. Seismic velocities derived from the impedances indicate a velocity reduction of 30 %. Thus, time-lapse VSP imaging at Ketzin shows that monitoring of small injection amounts is feasible.