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Seismic Monitoring of Land Carbonate Reservoirs: Results from a CO2-EOR Demonstration Project

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ABSTRACT

It is widely accepted that monitoring fluid or pressure changes in onshore carbonate reservoirs is a major geophysical challenge. A number of factors work together to increase the level of complexity including: (1) the high degree of reservoir heterogeneity, (2) the expected small effect of fluid changes on seismic amplitudes due to high rock stiffness, (3) low seismic resolution, and (4) limited data quality. In the present study, we use time-lapse seismic data to monitor changes in a carbonate reservoir in Saudi Arabia, which has undergone alternating periods of CO2 and water injection for a period of two years. Due to the high repeatability of the acquisition scheme and the 4D-compliant processing used, we have obtained high-quality data with an average estimated non-repeatable noise as low as 5%. Analysis of the difference amplitudes shows very encouraging results; a clear brightening in 4D amplitudes appears close to CO2 injector wells, while the same signal fades away when injection water replaces CO2. Starting from the detailed qualitative interpretation of 4D amplitudes, the paper then focuses on presenting an integrated interpretation approach to use 4D seismic data in a quantitative way. To achieve this objective, we consider the history-matched reservoir model. Fluid saturation and pressure changes from the simulation are transformed to elastic parameter changes through a calibrated rock physics model. Eventually, 4D seismic amplitudes are modelled, to which we add a varying level of 4D noise. At this stage, we can calibrate different statistical models between 4D seismic amplitudes and local cumulative CO2 for different geological scenarios. This analysis allows estimating average amounts of CO2 corresponding to the observed 4D amplitudes. It also allows us to show that for any combination of geological scenario and 4D noise level, there exists a minimum detectable thickness of CO2 below which the estimated uncertainty is greater than the estimate. Below this threshold, we can only estimate a probability of CO2 presence based on a cross-validation analysis. The second step of the workflow consists in estimating the local noise content of real 4D amplitude differences by analyzing differences between consecutive 4D datasets. By combining this result with a geological scenario map, we estimate 4D threshold maps. Finally, the latter are used in conjunction with estimated CO2 maps to produce maps of CO2 detection probability.