Rock physics inversion for CO_2 injection at Sleipner

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Introduction

Various geophysical techniques are used prior to and during the CO_2 injection process to characterize the changes in the subsurface properties. Several methods (for example, imaging and tomographic methods, amplitude versus offset analysis) are used to quantify the effect of CO_2 injection on seismic properties. In this context, the high-resolution results provided by full-wave inversion (FWI) (Virieux and Operto, 2009) can be very useful to derive rock physics properties. In our work, we use a rock physics tool with similar two-step workflow as described by Dupuy et al. (2016) to characterize selected rock physics properties of the Sleipner CO_2 storage pilot.

Methods

We use rock physics inversion based on Biot-Gassmann theory (Pride, 2005) for the Sleipner baseline well data. This extended Biot theory allows describing the porous sandstone saturated with brine (before injection) and partially saturated with brine and CO_2 (after injection). The rock physics tool allows computing viscoelastic properties from the poroelastic properties (rock and fluid phases). We use the Neighborhood Algorithm (Sambridge, 1999) to solve the inverse problem. This method is searching for the global minimum over the whole model space domain. The discrepancy between observed data (viscoelastic properties derived from input data) and calculated data (viscoelastic data computed from the rock physics properties by forward modeling) is described by a misfit function following the L2 norm.

Results

The log data from Well 15/9-16 before the CO_2 injection is used. We compute empirically S-wave sonic velocity using the empirical Vernik's relation (Mavko et al., 2009). We carry out the estimation of dry bulk and shear frame moduli (K_d and G_d) and the inversion is applied to the whole log data (Figure 1). The combination of P- and S- wave velocities and density (V_P, V_S, ρ) inputs provide the most stable estimation, which appears to be consistent with the estimated values from the geological study of Lindeberg (2013). Sensitivity tests under different CO_2 saturated conditions are performed in order to figure out how the CO_2 saturation and properties can be estimated from results provided from FWI. A priori parameters are defined based on existing studies on Sleipner. The sensitivity tests show that brine saturation S_W is better estimated when more than only P-wave velocity data is provided, but using only P-wave velocity is sufficient to get reliable results. The combination of V_P, V_S and ρ input make the estimation more accurate. In addition, other sensitivity tests have been carried out in less optimal cases (if the rock physics model is not perfectly known and if the CO_2 properties are not defined) and suggest that the use of additional input data, especially S- wave velocity and P-wave quality factor are required to get a good estimation of CO_2 saturation.

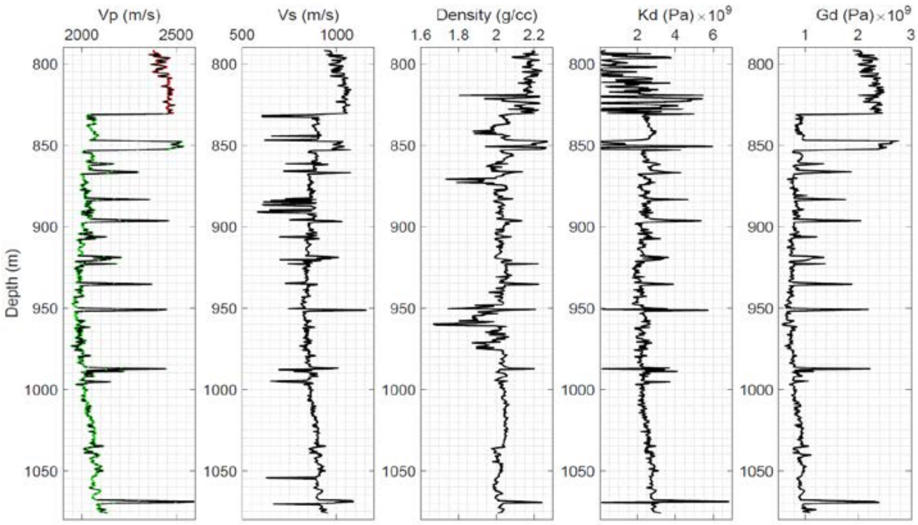

Figure 1: V_P, V_S and density responses from the Well 15/9-16 (3 left panels). Dry bulk and shear moduli (2 right panels), which are derived by rock physics inversion.

Conclusions

We demonstrate the use of rock physics inversion for estimating CO_2 saturation and rock frame properties at Sleipner CO_2 storage site in the North Sea. We model the effect of various CO_2 saturations on viscoelastic properties of the Sleipner sediments. The CO_2 saturation can be well estimated when enough input data is provided. Using well log data, the S-wave velocities are coupled using empirical relations with the P-wave velocities and density from well log to estimate the rock frame moduli before CO_2 injection at the Utsira sand formation.

Acknowledgements

This work has been produced with support from the uniCQue project and the BIGCCS Centre, performed under the Norwegian research program Centres for Environment-friendly Energy Research (FME). The authors acknowledge the following partners for their contributions: Gassco, Shell, Statoil, TOTAL, ENGIE and the Research Council of Norway (193816/S60, 233716/E20) for their support. We also thank Malcolm Sambridge for providing NA code in our study.

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