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Tuning Effects in P-wave Reflections from a CO_2 Injected Saline Aquifer: A Preliminary Appraisal

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Summary

Tuning effect in the seismic response of a deep saline aquifer subject to CO_2 injection is appraised through numerical simulations. The synthetic models mimic the known geology of a prospective site in the Bécancour area, Québec. Seismograms are computed using a poroviscoelastic solution of the seismic wave equation. Preliminary results indicate that tuning effect can have a surprising effect on the amplitude of a P-wave reflected at a CO_2 saturated reservoir, and might even invert the sign of a time-lapse anomaly

Introduction

In a carbon market context, appraisal and verification of stored CO_2 should be integrated components of CCS projects. As such, monitoring programs of CO_2 injection should ultimately allow for the quantitative estimation of CO_2 saturation in the reservoir. Geophysical methods are challenged in this respect, and multi-method approaches should be favored. Gravity monitoring should be helpful for mass balance estimation, especially if downhole gravimeters can be positioned close to the reservoir. Nevertheless, seismic methods will always play a central part in monitoring programs due to their high resolution compared to other geophysical methods. AVO is used in reservoir characterization to interpret seismic data quantitatively in terms of fluid properties (Avseth et al., 2005). Because supercritical CO_2 has very contrasted physical properties compared to brine, it is expected to produce a strong AVO anomaly and appears promising for monitoring programs (Brown et al., 2007).

As CO_2 rises within heterogeneous formations due to buoyancy forces, it may become trapped underneath discontinuous horizontal flow barriers. Such barriers are usually thin compared to the seismic wavelength and likely cause significant tuning effects. Depending on type of reflectivity pattern, tuning effects may have a tremendous impact on AVO responses (Chung and Lawton, 1999), for which some correction factors can be computed (Bakke and Ursin, 1998). In this paper, we investigate how tuning effects might distort the AVO response of CO_2 injection in a saline aquifer.

Theory and Method

Synthetic models are built based on our current knowledge of a prospective site in the Bécancour area in Québec (Konstantinovskaya et al., 2010). Well logging data from a number of wells in an approximately 5 by 10 km^2 sub-area were used to determine representative vertical profiles of temperature, pressure, porosity, salinity and mineralogy. Besides, seismic profiles also reveal horizontal layering in this part of the reservoir (Claprood et al., 2010). To evaluate tuning effect on the coefficient of reflection, the response of a two-layer model is compared with that of the sedimentary sequence as determined from the well log data. The depth of the interface is 714 m, which correspond to the end of the Utica Shale and the beginning of a transition zone toward the Trenton Limestone. In this work, we make the simplifying assumptions that the earth is 2D, that the CO_2 has fully migrated to the top of the reservoir, and in the multi-layer case, the thickness of the CO_2 saturated portion of the reservoir is 30 m. Also, to make the comparisons tractable, the upper shale layer has exactly the same properties in all scenarios. The P-wave phase velocity is 4500 m/s in this layer, representative of the values found in the area at the depth of the interface.

The seismograms were modeled with a 2D implementation of the poroviscoelastic formalism described in Carcione (1996, 1998). Fluid properties were computed following to Batzle and Wang (1992) using available log data. Elastic moduli of the solid and drained matrix were obtained from the mineralogy content, respectively after application of Hashin-Shtrikman averaging and the Hertz-Mindlin contact theory (Carcione et al., 2006; Mavko et al., 2009). Figure 1 shows the models. Due to the relatively low porosity of the reservoir (between 2 and 7% in the multi-layer case, 5% for the two layer model), the relative effect of the CO_2 is somewhat modest.

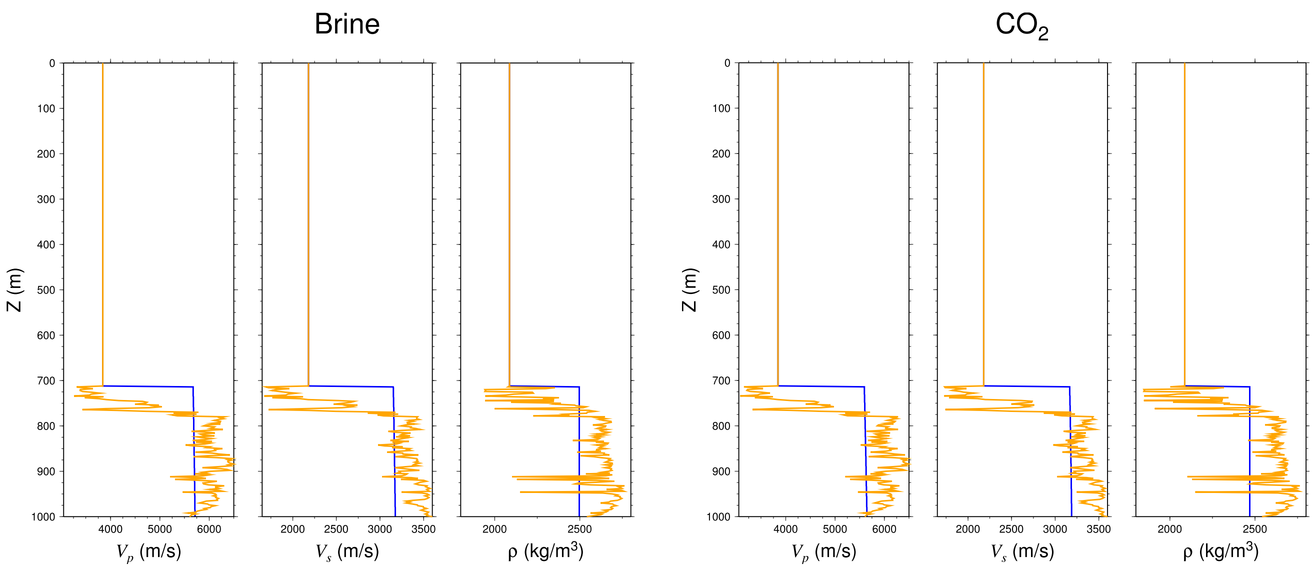

Figure 1: Synthetic models. Phase velocities are computed from the rock and fluid properties (Carcione, 1998).

Results

The models were excited with a 50 Hz Ricker function. To get a wide angular coverage, the modeling domain extends beyond 3500 m horizontally. The presence of fine layers has a strong effect on wave propagation, as can be seen in Figure 2.

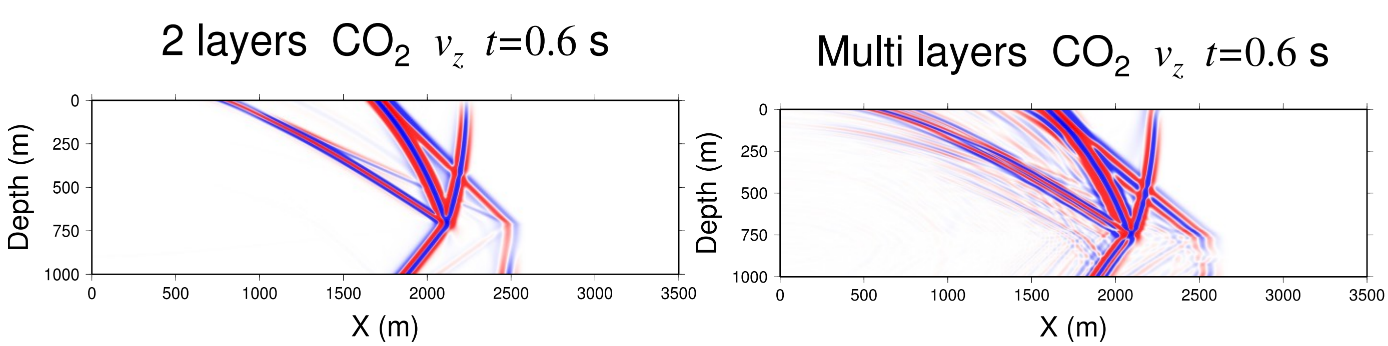

Figure 2: Snapshots of the vertical component of particle velocity for CO_2 injected models.
Color scales are not linear to enhance low energy waves.

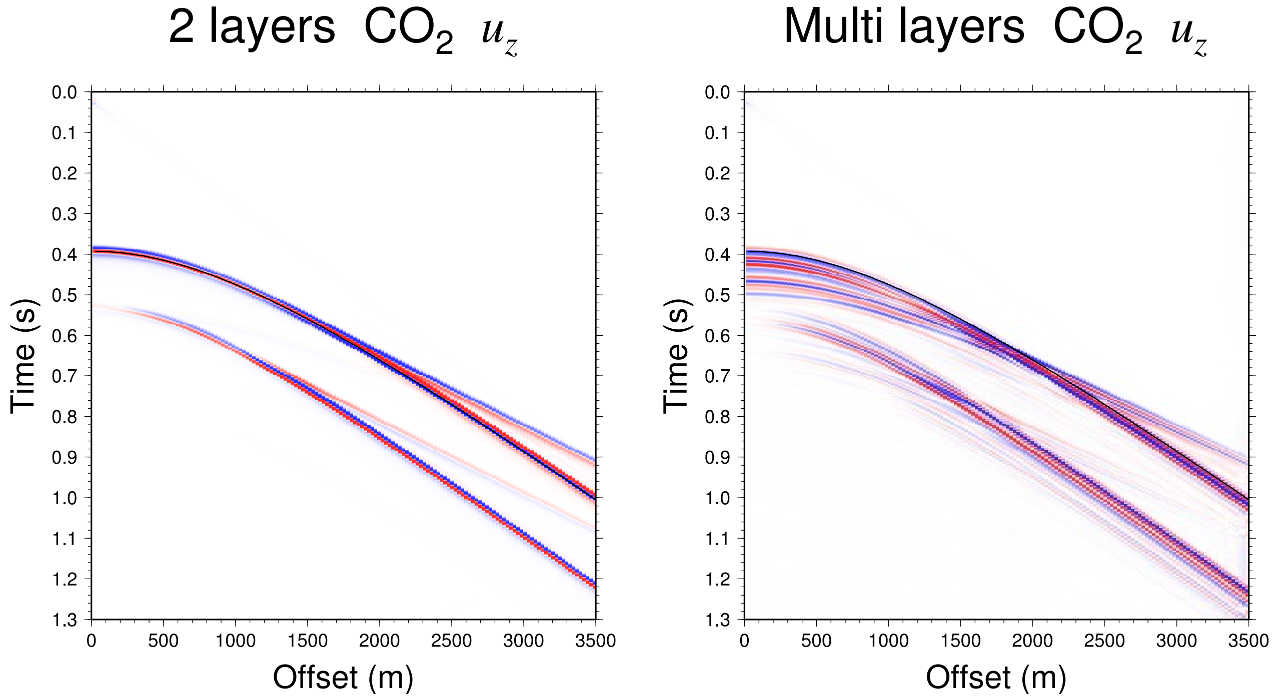

Figure 3: Common midpoint gathers for CO_2 injected models.

The particle velocity seismograms were converted to displacement, and a *Vt* spreading correction was applied to the traces. Two common midpoint gathers of the vertical displacement are shown in Figure 3. In the particular case considered here, the transition zone has for effect to invert the polarity of the reflection. The thin layering also cause a number of events of different time width to appear. The reflected amplitude as a function of angle of incidence is also affected by the thin layering, as illustrated by Figure 4. These values were picked along the NMO curve. The reflection is stronger for the multi-layered CO_2 saturated reservoir, in opposition to the two-layer CO_2 saturated case. For comparison, the reflection coefficient computed using Zoeppritz relations are shown in Figure 5.

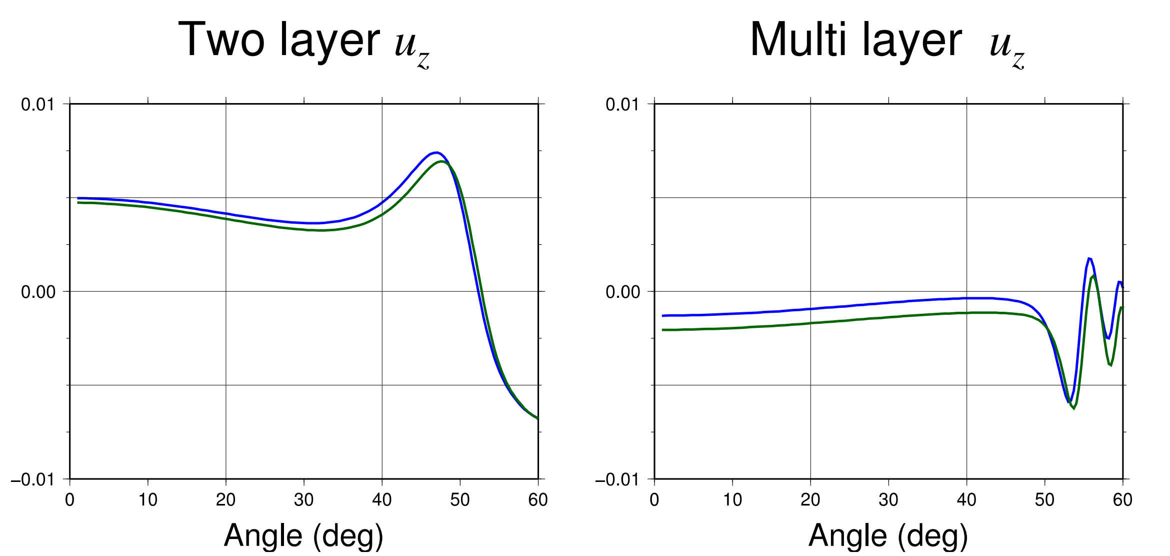

Figure 4: Reflected P-wave amplitude as a function of angle of incidence. Blue curves: brine saturated reservoir, green curves: CO_2 saturated reservoir.

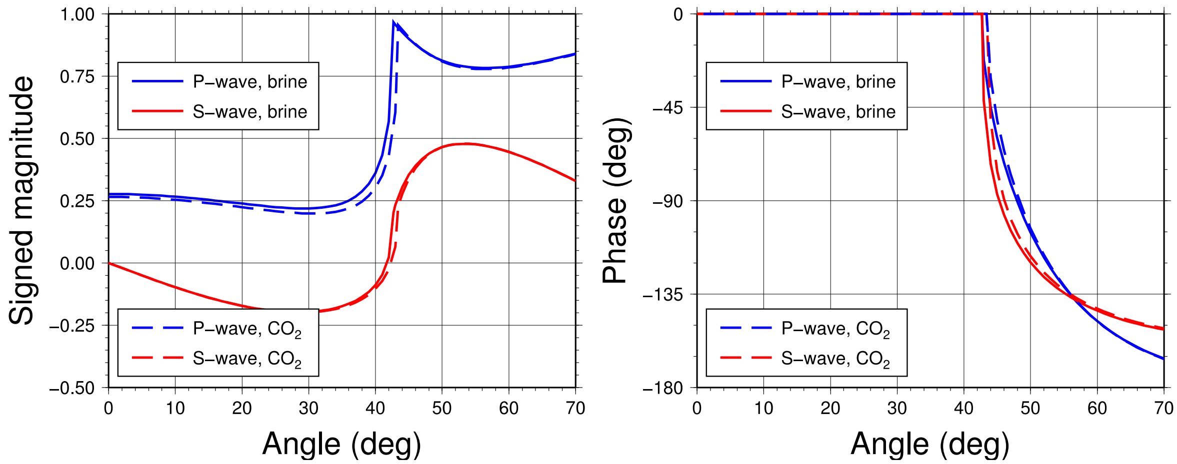

Figure 5: Zoeppritz reflection coefficients for the two-layer model.

Conclusions

Preliminary results indicate that tuning effect can have a surprising effect on the amplitude of a P-wave reflected at a CO_2 saturated reservoir, and might even invert the sign of a time-lapse anomaly. Work is currently going on with hydrogeologists to model the spatial distribution of the CO_2 saturation and get a more representative model for our analyses. Future work will also consider the anisotropic nature of the cap rock and loss mechanisms. We are also investigating means to calibrate the physical properties of the models to laboratory measurements.

Acknowledgements

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