Title

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Introduction

Seismic imaging has been used very successfully to map the location of injected CO_2 at the Sleipner and Weyburn Projects (Chadwick et al., 2005; White, 2005). Theoretical calculations by Myer et al. (2003) suggested that the detection limits for cone-shaped accumulations would be in the range of 10,000 – 20,000 tonnes of CO_2. However, based on actual experience, lower limits for detection of CO_2 accumulations at the reservoir depth have been estimated to be in the range of several thousand tonnes of CO_2. Recently, a VSP obtained at the Frio Brine Pilot demonstrated the ability to detect as little as 1600 tonnes of CO_2.

The ability to detect small quantities of CO_2 that have unintentionally escaped from the storage formation is essential for providing early warning that the project is not performing as expected. The purpose of this study is to assess, from a theoretical and practical perspective, the minimum amount of CO_2 that could be detected using surface seismic imaging as it migrated towards the surface. To this end, calculations have been made to assess the seismic response of accumulations of 1,000 tonnes of CO_2 at depths of 1300 m, 1000 m, 800 m, and 500 m below the land surface. Sensitivity studies have been conducted to assess the influence of the accumulation thickness and saturation. Sensitivity studies will also be done to determine if even smaller accumulations could be detected at a depth of 500 m or less. In addition, the influence of multi-layer accumulations will also be assessed.

Methodology and results

The conceptual model used for this study is shown in Figure 1. It assumes that CO_2 which has escaped from the storage formation accumulates in a secondary trap above storage horizon. The accumulation is cone-shaped, which is a reasonable assumption for CO_2 that has migrated upward, subject to buoyancy forces and capillary trapping. For each depth below the ground surface, that is 500 m, 800 m, 1000 m, and 1300 m, the density of the CO_2 is obtained using the NIST Mixture Property Database (1992). The pressure is assumed to be hydrostatic and the geothermal gradient assigned to be 3 deg. C/km. Based on these densities, the saturation and the thickness of the CO_2 accumulation, it is possible to calculate the radius of the cone-shaped accumulation. Calculations are shown in Figure 2 for a 1,000 tonne accumulation with a range of thicknesses and a saturation of 5%. Similar calculations are also made for saturations of 10% and 20%. As expected, as the accumulation moves towards the surface, it becomes significantly larger.

Accumulations of these sizes are incorporated into a realistic model of the subsurface based on a geologic cross section of the Schrader Bluff Oil Field in Alaska. A petrophysical model is used to parameterize the seismic velocity based on the lithology, as well as, the density and compressibility of CO_2 at these depths. Forward seismic simulations are then conducted to generate synthetic seismic cross sections. Fully elastic 2D simulations are carried out in the shot domain with and without noise. Variable offset noise is simulated, ranging from a signal to noise (SNR) of 10 to 1 at the near offsets to a SNR of 1 to 1 at far offsets. The synthetic shot gathers are then processed with Kirchhoff time migrations to produce migrated stack sections. Examples of the synthetic seismic sections for the accumulations at depths of 800 m and 1300 m are shown in Figure 3. As shown, the small accumulations are evident in the synthetic data. However, to obtain a more realistic assessment of whether or not these accumulations are evident, synthetic random "noise" is added to the synthetic data before it is migrated. An example of one such calculation is provided in Figure 4.

Based on these types of simulations, a systematic study of the minimum accumulation size is carried out. Sensitivity to saturation, accumulation thickness and the presence of accumulations at multiple depths is also assessed.

Conclusions

Under favorable geological conditions, seismic methods can detect small accumulations (~ 1,000 tonnes) of CO_2, particularly as the CO_2 moves closer to the ground surface. Once shallower than 800 m, the density decreases markedly and the compressibility increases as it CO_2 transitions from supercritical to gas phase. Both of these factors significantly improve the seismic detection limits as CO_2 migrates towards the land surface. This systematic study is an important step towards developing approaches for detecting leakage from the storage formation long before it could reach the ground surface.

References

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Figures

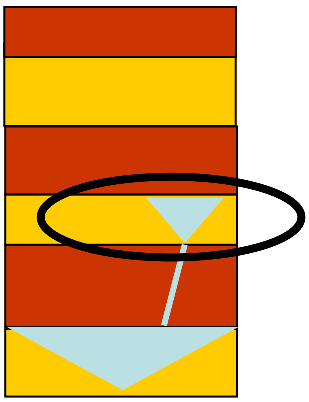

Figure 1.Conceptual model for accumulations of CO_2 above the storage formation used for the seismic simulations.

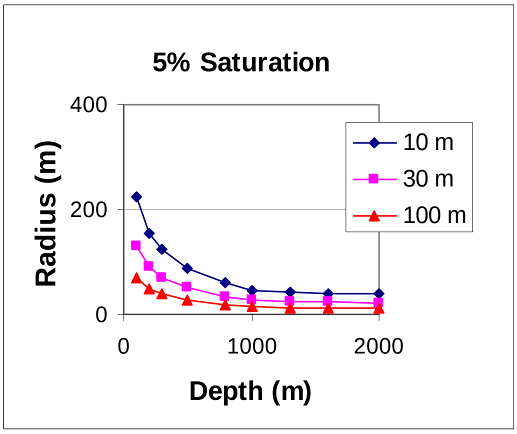

Figure 2. Calculated radius of a 1,000 tonne cone-shaped accumulation of CO_2 as a function of depth below the ground surface (100 to 2000 m) and the thickness of the accumulation (thicknesses of 10, 30 and 100 m). A 5% saturation of CO_2 within the accumulation is used for this calculation.

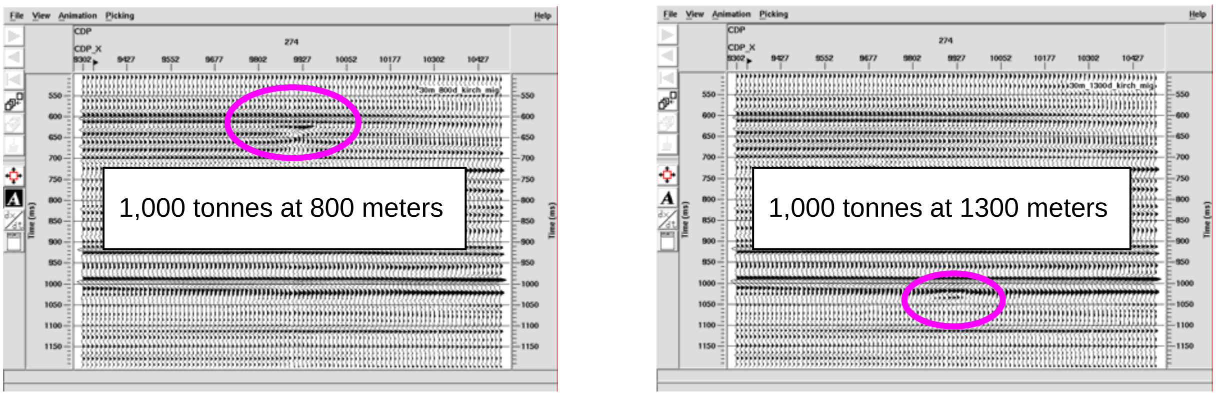

Figure 3. Simulated seismic responses for 1000 tonne accumulations at depths of 800 m and 1300 m. A saturation of 20% is used for these calculations and the thickness of the accumulation is 30 m. As illustrated, the seismic response for the accumulation at a depth of 800 m is greater than the accumulation at a depth of 1300 m. This is expected due to the larger radius of the accumulation as well the lower density and higher compressibility of the CO_2 at the shallower depth.

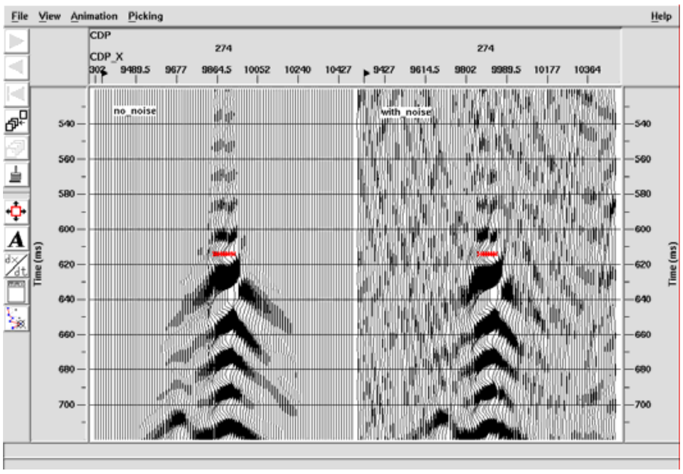

Figure 4. Migrated seismic data for the accumulation at 800 m with and without offset-dependent synthetic noise. Note the accumulation is still evident with the added synthetic noise.