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Fluid Substitution and Seismic Modelling in a Sandstone Aquifer

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Summary

Fluid substitution and seismic modelling were applied in order to evaluate the Paskapoo Formation as a potential CO_2 geological storage unit and for the purposes of developing seismic monitoring technology. The first stage of this project deals with the application of the Gassmann substitution model using well data and evaluation of property variations due to CO_2 saturation changes. Seismic modelling was undertaken in the area of interest simulating pre, during and post CO_2 injection scenarios. From Gassmann calculations it was found that the P-wave velocity decreases between 0 to 20% CO_2 saturation and starts to rise subtly at 30% CO_2 saturation, whereas the S-wave velocity increases directly proportional to CO_2 saturation. In this reservoir, the P-wave velocity decreases approximately 7%, the S-wave velocity increases 0.8 %, V_p/V_s decreases an average value of 8% and the basal reflector of the sandstone reservoir exhibits a time delay of 1.6 msec. From seismic modelling it was found that the injection zone can be delineated in the CDP stack section through an amplitude change the top reflector and a time delay for the basal reflector. The reflectivity was evaluated using the Shuey approximation and qualitative observations of the sections, showing a decrease in the reflectivity with increasing CO_2 saturation, with a major drop in the first 10% and a further amplitude decrease with offset (higher incident angles). These parameters allow us to estimate the conditions that would help to interpret the real data in further phases of this study.

Introduction

The inevitable and fast increase of the greenhouse gas concentrations and hypothesized global warming, constitute one of society's major concerns presently. Excess of CO_2 in the atmosphere is considered by many to be the principal cause of the problem, affecting the natural equilibrium. CO_2 sequestration in geological sites represents a viable solution or at least a way of mitigation. The idea of this method is to capture CO_2 produced by anthropogenic or natural point sources and inject it into a porous layer surrounded by non porous layers to trap the gas (Hovorka, 2008).

The main objective of this project is to evaluate Paskapoo Formation as a potential test site for developing seismic monitoring technology for CO_2 storage in sandstone aquifers. The Paskapoo is a Tertiary Formation that constitutes an important ground water reservoir target having some qualities that make this possible such as high-porosity coarse-grained sandstone channels (Grasby et al., 2008). The study site is located close to the Rocky Mountains Foothills, Southwest of Calgary (Figure 1). The initial stage of this project is based in fluid substitution and seismic modelling in order to evaluate the feasibility of monitoring CO_2 injected in a possible sandstone target inside the Paskapoo Formation.

Figure 1: Site location (red dot) (Bachu et al., 2000)

Method

A fluid substitution model was performed using well information to estimate the effects and changes due to CO_2 injection. Synthetic seismograms were generated for each CO_2 saturation value. Gassmann equations were applied in order to evaluate changes in the P-wave and the S-wave velocity. Finally a 2D seismic model of the area was created with the respective density and velocity parameters obtained from well information. The zone of injection is defined inside the model. Six (6) CDP stack sections were created: 0%, 20%, 40%, 60%, 80% and 100% CO_2 saturation, changing parameters for each saturation stage. This model provides some ideas about the seismic response depending on the CO_2 saturation and the evolution of the injection process.

Results

In the synthetic traces that go from 0 to 100% CO_2 saturation, the amplitude values changes across the substitution in the top reflector (380m) with CO_2 increment (Figure 2). Looking at changes in P-wave velocity, there is an evident velocity reduction, highlighted at 390-400m. The main drop occurs from 0 to 20% CO_2 saturation, but it can't be recognized any major variation for higher saturation values.

The results obtained were supported by direct application of the Gassmann equation. Figure 3a shows how the P-wave velocity values drop abruptly between 0 to 20% CO_2 saturation, and starts to increase at 30% saturation, having a general decrease of 7%. On the other hand the changes in S-wave velocity are not so evident, having a directly proportional increase with CO_2 saturation, but in a magnitude of only 0.8%. In addition to this, the time shift of the basal reflector, present in synthetic traces and seismic can be calculated showing the major time delay at the first saturation stages and slightly diminishing in the further stages (Figure 3b).

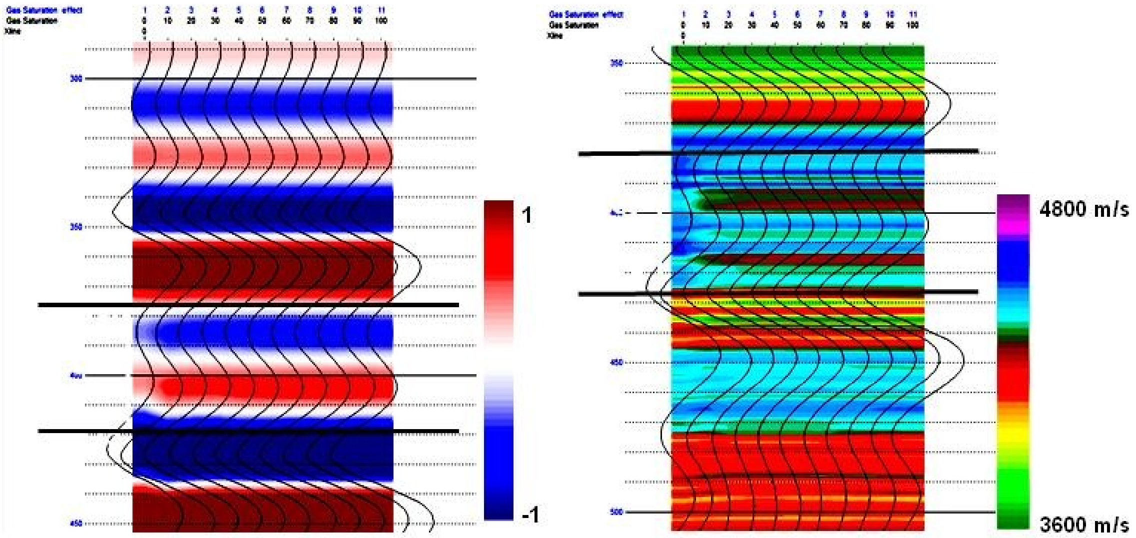

Figure 2: Synthetic traces, amplitude (left) and velocity (right) variation with increasing CO_2 saturation. Target zone: 380-425m

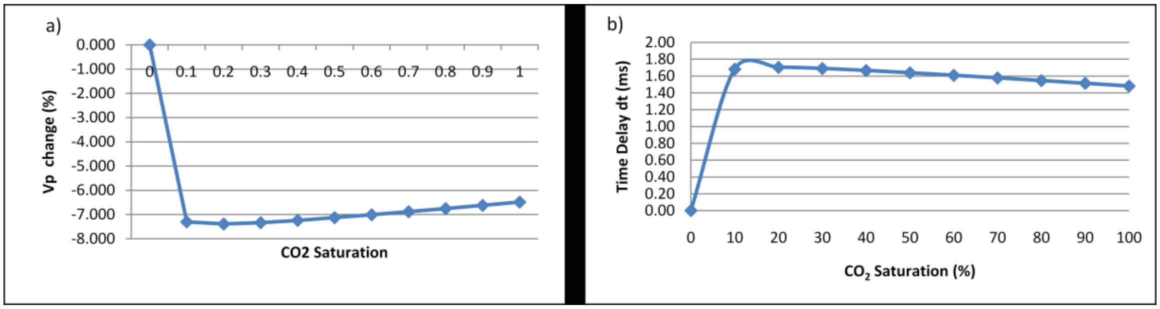

Figure 3. a) P-wave velocity change versus CO_2 saturation. b) Time delay vs. CO_2 saturation

The effect of the CO_2 injection can be appreciated by subtracting each of the CDP stack sections from the 0% CO_2 section. Figure 4 shows the difference between the 0% CO_2 section and the 100% CO_2 section. As is expected, the rest of the traces outside the area of interest were cancelled while the top and bottom reflectors of this region are highlighted due to the difference in amplitudes and travel times of the event from the base of the injection horizon.

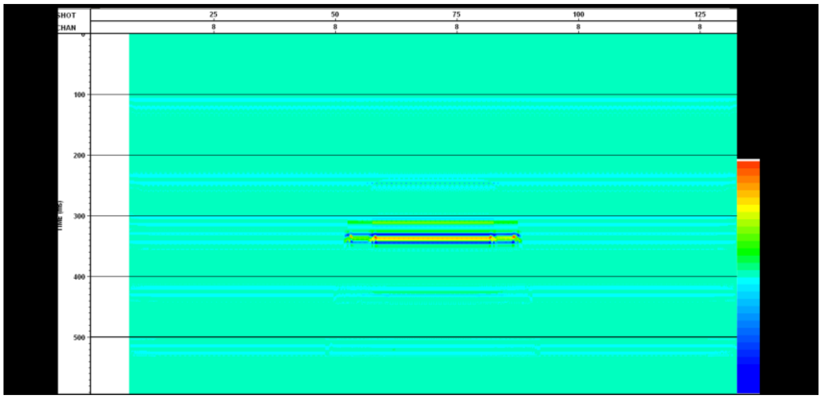

Figure 4. Difference between 0% CO_2 and 100% CO_2 saturation CDP stack section

In addition to the comparison between seismic sections, AVO analysis was undertaken. Applying Shuey's approximations, the changes in reflectivity due to CO_2 saturation were evaluated. The final P-wave reflectivity (R_{pp}) was calculated with different angles of incidence to evaluate the changes of reflectivity with offset and saturation. The approximation by Shuey (1985) was applied for three CO_2 saturation stages: 0%, 20% and 60%. Figure 5 confirms that the reflectivity diminishes with the increment in the incident angle. All the curves have the same tendency, but with the CO_2 increment the reflectivity values decrease. The major drop occurs for 0% to 20%.

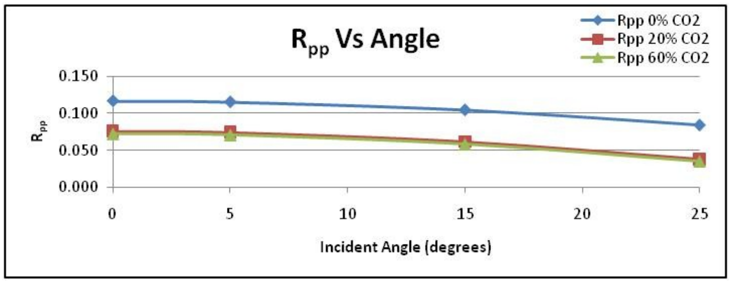

Figure 5. R_{pp} Vs Angle of incidence with different CO_2 saturation stages (0%, 20% and 60%).

Conclusions

- Paskapoo Formation has suitable qualities for a test CO_2 geological storage site; it has considerable section of clean sandstone and being a shallow objective will reduce monitoring complexities and cost.
- Gassmann theory is a practical and useful tool in fluid substitution models. Its direct evaluation and synthetic seismogram variation reflects the effects of CO_2 saturation changes. There is a recognizable alteration of rock properties and seismic patterns due to CO_2, mainly in the P-wave velocity.
- There is a measurable time delay of the basal reflector and an amplitude decrease with increasing CO_2 saturation and with the angle.
- The majority of the changes in properties occur during the first saturation stages (from 0 to 20 % CO_2 saturation). This mean that even with a small concentration of this fluid it is possible to distinguish changes in seismic.

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