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CO2CRC/Otway Project - Influence of Geological and Reservoir Parameters on Expected Time-lapse Seismic Signal

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SUMMARY

In the field of CO₂ storage, one important goal is to be able to prove that the injected CO₂ is safely stored, and that no leak is occurring. Time-lapse seismic is one of the most powerful tools available for this purpose. However, it is generally used in a qualitative way, to map the injected CO₂. Several attempts have been made to use it quantitatively, which are based on the measured time-shifts throughout the seismic volume.

Here, we assess the impact of geological and reservoir parameters on the predicted time-lapse signal, which is a first step towards quantification. Uncertainties occur when trying to evaluate the expected time-lapse seismic signal. Porosity and permeability are constrained at the wells, but, as is standard in the E&P industry, statistics are used to distribute them throughout the reservoir volume, which is a source of uncertainty. Some reservoir parameters need to be measured, and are poorly constrained for CO₂. Our results show that these parameters have an impact on seismic signal prediction, which is not overwhelming (generally below 30%).

Introduction

CO₂ injection started in the CO2CRC/Otway project in March 2008, for a total duration of two years. The total amount of CO₂ injected in the Waarre C formation should reach 100,000 tons by the end of the project. Otway is a depleted gas reservoir, and residual gas is trapped. It is thus a challenging project for geophysics, since the expected time-lapse signal is weak (Urosevic, 2008).

In this context, we perform 2D and 3D finite difference simulation, so as to retrieve the expected seismic signal before and after injection, hence the expected time-lapse signature. We create a velocity model before injection using the available log data, and the interpreted surface seismic horizons. Using the available reservoir simulation (Xu Qiang, 2005), coupled with a rock physics model based on Gassman's equation (Wisman et al., 2008), we compute a velocity model after injection.

In this workflow, several parameters are constrained at the wells only, and are distributed using a statistical approach. This is the case for porosity and permeability. These random realizations introduce an error on the final time-lapse signal prediction. Other parameters such as relative permeability, capillary pressure, hysteresis, have been measured for very few samples (Bennion and Bachu, 2005, Perrin and Benson, 2008). The relative permeability for the Waarre C formation has been measured on one core, which might not be representative of the entire formation (J. C. Perrin, personal communication).

Our goal here is to assess the influence of these uncertainties on the modelled time-lapse seismic signal and to study their propagation throughout the workflow. If we want to be able in the future to relate time-lapse seismic signal and amount of CO₂ stored underground, this step is fundamental.

Method

We build a velocity model before injection using available logs at the injection wells, CRC-1. We assume that velocity is dominated by compaction, and that interfaces visible in surface seismic data are recognizable in the high frequencies of the logs. As a consequence, we low-pass filter compressional velocity, shear velocity, and density logs, and we propagate the filtered log in 1D. We high-pass filter the same logs, and we propagate the information following the interpreted surface seismic horizons (Dance et al., 2007). We then sum the two sets of properties and obtain our initial velocity model. Although very simple, this approach is sufficient to reach the goal of our study.

To obtain a velocity model after injection, we use available models resulting from the work done over the years by the researchers of CO2CRC. The static model (Dance et al., 2007) describes the porosity and permeability throughout the field. These properties are known at the three wells present in the area: the injection well, CRC-1, which has been drilled as part of the CO2CRC/Otway project; the monitoring well, Naylor-1, which used to be a producing well; another former producing well, Naylor-South. Then, statistical distribution is calculated to populate the reservoir volume, following the interpreted facies (Dance et al., 2007). This is the classical workflow traditionally used in the E&P industry.

This static model was used to build a reservoir model (Xu Qiang et al., 2006). History matching was performed and the measured pressures at the Naylor-1 well (during production) were matched (Xu Qiang et al., 2006).

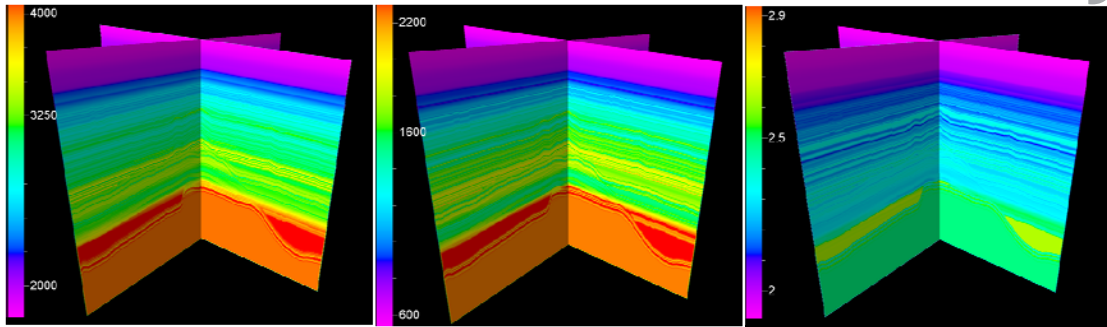


Figure 1: Velocity model before injection. Left: compressional velocity. Middle: shear velocity. Right: density. These are 3D properties, and the central inline and crossline are represented.

The outputs of the reservoir model are used in a rock physics scheme (Wisman et al., 2008) to obtain velocity (both compressional and shear) and density after injection. This rock physics scheme is based on Gassman's equation, which is valid in the low frequency range of seismic data. Wood's law is used to obtain the fluid bulk modulus (also valid for seismic frequencies), and K_{dry} is derived from laboratory measurements (as described in Siggins, 2006).

The successive use of these three steps (static model, dynamic model, rock physics) allows us to obtain a velocity model after injection (see also Janssen et al., 2006 who use a similar approach for this).

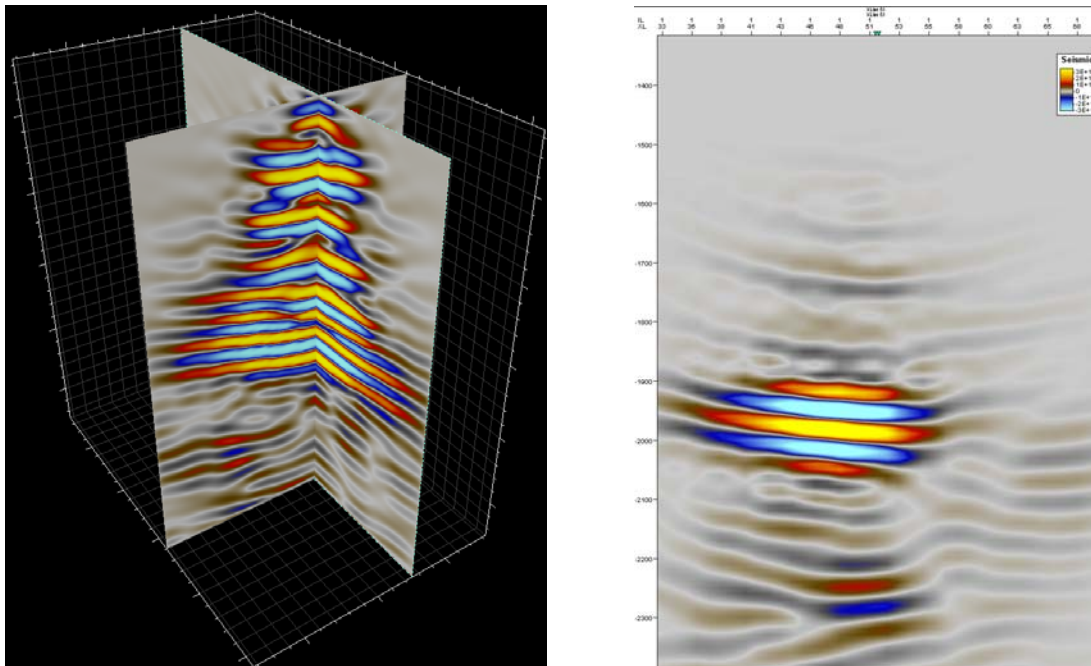


Figure 2: Left: Synthetic migrated 3DVSP volume before injection. Right: Synthetic time-lapse signal, the central inline is represented.

We use 2D and 3D finite difference modelling to simulate seismic acquisition before and after injection. We use a 3DVSP (3D Vertical Seismic Profile) geometry or walkaway geometry, with eight receivers. We apply the principle of reciprocity, which allows us to minimize the computational time. One 3DVSP is calculated in 60 hours using 8 CPU and ~28 Gb of RAM. However, the plume is not mapped entirely, and a surface seismic geometry would be more

appropriate, and this is one of our goals in the future. The adopted processing sequence is a standard processing chain: parametric wavefield separation (Leaney, 1990), waveshape deconvolution, wave equation migration. The migrated volume and the time-lapse signal are shown on Figure 2.

Propagation of uncertainties

When building the static model, assumptions were made on porosity and permeability. Our purpose is to see how these assumptions propagate throughout the workflow. We run the following simulations: we rebuild the static model using log information at two wells only (Naylor-1 and Naylor-South), and we use the initial static model built with logs at all three wells (CRC-1 additionally). We then run the reservoir simulation using each of the two static models, and apply the rock physics scheme to retrieve velocity models in the 2 configurations. This simulates what happens in reality: a static model becomes increasingly accurate with an increasing number of wells. The influence of porosity on the results is shown on Figure 3.

At the reservoir simulation stage, the results are influenced by relative permeability, capillary pressure and hysteresis: very few curves are available in the literature (Bennion and Bachu, 2005, Perrin and Benson, 2008), including one curve of relative permeability in the formation of interest, Waarre C (Perrin and Benson, 2008). The core used for Waarre C comprises some barriers of permeability, and it might not be representative of the entire formation (J. C. Perrin, personal communication). The available curves of relative permeability show a high degree of variability, and a different shape of the CO₂ plume is predicted by the reservoir simulation when a different curve is used. To test these parameters, we use all possible combinations of curves available in the literature, in an approach similar to Cinar, 2008, Van der Meer and Wees, 2006, Kumar et al., 2005 etc... The results obtained with three different curves of relative permeability are shown on Figure 3.

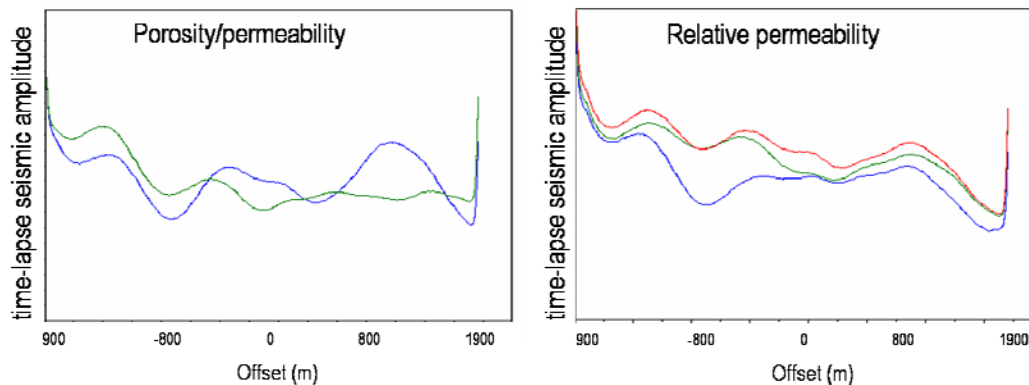


Figure 3: Time-lapse seismic amplitude along the reflector of maximum amplitude. Left: influence of porosity and permeability. The blue curve is obtained with a static model built with the data of two wells only, while the green curve is obtained with a static model based on all three wells. Right: Influence of relative permeability and capillary pressure, three different sets of curves are used (Bennion and Bachu, 2005).

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In this work, we simulate synthetic 3DVSP and walkaway data before and after injection to assess the accuracy of the theoretical time-lapse signal. The ultimate goal is to compare this estimate with the actual seismic signal so as to be able to assess the accuracy at which the amount of CO₂ injected underground can be determined via time-lapse seismic. This goal is

very challenging in the case of the CO2CRC/Otway project, because the expected seismic signal is weak. However, the methodology can be applied to other projects of CO2 storage.

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