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Seismic Monitoring of CO2 Geosequestration in Otway Basin, Australia

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SUMMARY

CO2CRC Otway Project is the Australia s first demonstration of the deep geological storage of CO2. CO2 has been injected in a depleted gas field at the depth of 2050 m and then will be injected in saline aquifer at the depth of around 1 km. For time lapse studies, we had four different 3D seismic surveys available. Besides of a large 3D seismic volume acquired in the year 2000 prior gas production of the reservoir, three sequential 3D surveys were acquired at the same site but over a smaller area: baseline survey in 2008 and two monitoring surveys in 2009 and 2010.

We concentrated on repeatability of 4D seismic data acquisition and processing. This led us to the results which allow to define CO2 location in the reservoir and proves that time-lapse seismic is a valuable tool in CO2 monitoring even in on-shore case.

Introduction

There are several large CO2 geosequestration projects in the world. As this number is growing by the day, monitoring the distribution and containment of CO2 in the injected strata becomes critical to the entire operation and inseparable from CO2 capture and storage processes. Different monitoring projects involve application of different variety of geophysical, geotechnical and atmospheric studies which aim to directly or indirectly verify containment of CO2 in the reservoir and in some cases detect CO2 movement through the reservoir with time. Central to most of CO2 monitoring studies is the application of time-lapse (TL) or 4D seismic methodology. The application of TL method relies on the differences in elastic properties produced by fluid replacement or fluid re-distribution in the reservoir. Geology mineral composition of the reservoir is typically assumed to be constant over several years and is excluded from the analysis. Fluid replacement effect is controlled by the depth (CO2 properties change abruptly with pressure and temperature), overall lithology and host rock properties. Detection of the net change in elastic properties by TL seismic depends on many factors such are: site specifics, acquisition and processing strategy and analysis methodology. It is typically assumed that offshore TL measurements are more viable than on-land. Moreover the effectiveness of the application of TL methodology for monitoring an onshore injection of CO2 into a deep, depleted gas reservoir has not been analysed before. In this study we concentrate on analysing and improving the repeatability of TL seismic over such case, that is deep, depleted gas reservoir in Otway basin, Victoria, Australia. Otway basin pilot project is certainly the first project where TL seismic methodology is applied to monitor CO2 injection into a deep depleted gas reservoir. The critical components of the TL program were: 4D seismic response prediction (Li et al., 2006) pre-base line repeatability studies, acquisition design (Urosevic et al., 2008) and data processing strategy (Shulakova et al., 2009).

In this presentation we discuss critical processing steps that enabled successful cross-equalisation of different vintages of seismic data taken during last 10 years over Waarre C reservoir. The success of the processing and data cross-equalisation we measure by using the methodology developed by Pevzner et al. (2009). Our results suggest that time-lapse seismic is also valuable tool for onshore CO2 monitoring, even in case of depleted gas reservoir.

Otway project time-lapse data acquisition

In 2000, the first large 3D seismic data were acquired in Otway basin that led to discovery of several gas fields. Of interest to our study is the Naylor gas field which is now used for CO2 sequestration tests. In 2008, first baseline 3D seismic data for Phase I was acquired (post CH_4 production and pre CO_2 injection). Due to objectives of the project, logistical issues (permissions) and limited budget the survey area was an order of magnitude smaller (1.6 x 1.9 km). The first and second monitoring surveys for the Phase I were acquired subsequently in the beginning of 2009 and 2010 with the same acquisition geometry including additional shooting sequence which will be utilised to form baseline survey for the Phase I of the project. Seismic survey parameters were listed in Table 1. At the same time seismic surveys 2009 and 2010 are baseline surveys for Phase II.

Table 1 Acquisition parameters.

Survey	**Pre-production**	**Baseline for phase I**	**1st monitoring for phase I & Baseline for phase II**	**2nd monitoring for phase I & Baseline for phase II**
Date	March 2000	January 2008	January 2009	January 2009
Bin size	20x20 m	10x10 m	10x10 m	10x10 m
Source type	Vibroseis, 3* 60,000 lb, Sweep frequency: 5-90	Weight Drop (concrete breaker),	IVI 15,000 lb, Mini-Vibe, Sweep frequency: 10-140 Hz	IVI 15,000 lb, Mini-Vibe, Sweep frequency: 10-140 Hz

	Hz	1350 kg, free fall from 1.2 m		
Receiver type	Sensor SM4, 10 Hz, 375 ohm	10 Hz geophones	10 Hz geophones	10 Hz geophones
Area	12.5 km x 10 km	1.6 km x 1.9 km	1.6 km x 1.9 km	1.6 km x 1.9 km

The main goal of TL seismic in Otway is to demonstrate that CO2 is in place by showing no time-lapse effect between surveys. However even small changes in near surface conditions, water table, ground noise, receivers and source positioning, etc. can affect data differencing results that is repeatability of successive surveys. While positioning errors were practically non-existent for the last three surveys, the source type has been changed from low energy Weight Drop (WD) source in 2008 to more powerful Mini-buggy source in 2009-2010. According to special repeatability analysis (Pevzner et al., 2009) S/N variability as function of the source strength relative to the background noise level is crucial. Source type is less important. Considering that the time-lapse set for phase I is at the same time base-line for phase II Otway project Mini-Vibe has been chosen as a preferred source for it provides data with S/N ratio twice bigger than the one produced with WD.

Time-lapse data processing

The critical point of the study was data processing and equalisation of baseline (2008) and the first monitor surveys (2009). False time-lapse anomalies could easily be created by different source generated noise. The difference between impact and vibrating sources can be striking when it comes to the generation of the coherent noise (Figure 1). Hence removal of such noise was the very important task. Careful selection of parameters for Radon filter yielded desired results (Figure 2).

Despite vastly different spectral content and S/N ratio between the surveys, we attempt processing and cross-equalisation of these three vintage sets by adopting somewhat different approaches to time-lapse processing of seismic data.

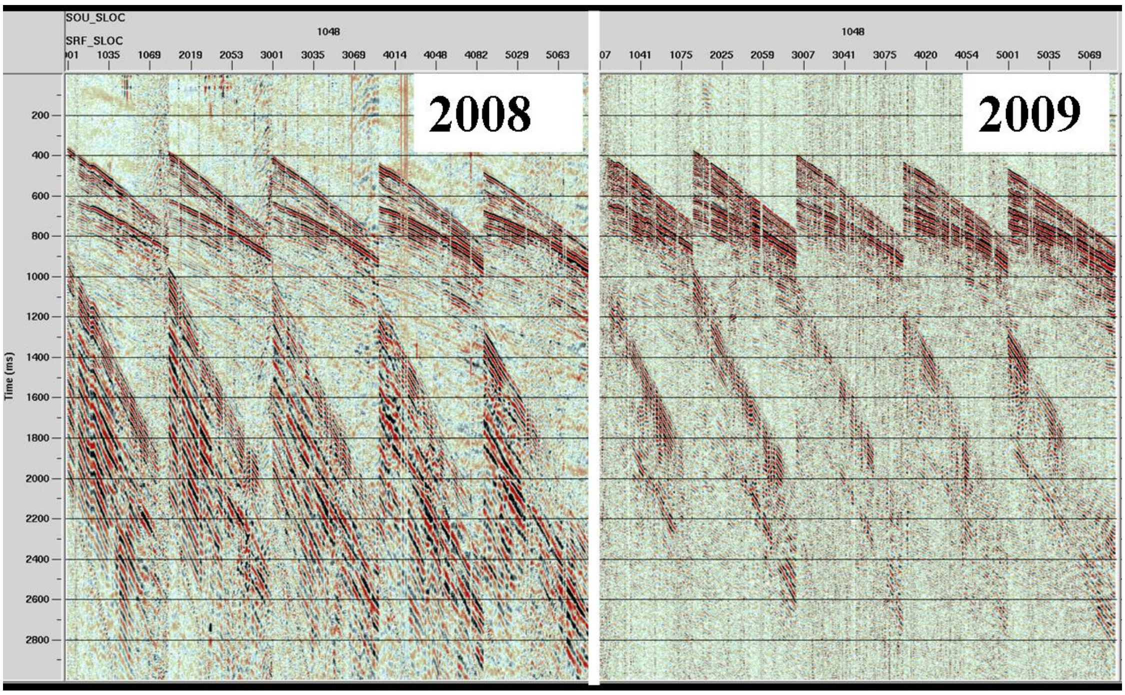


***Figure 1** Raw data example, the same common shot gather for 2008 (left) and 2009 (right) surveys.*

Main problems we encountered were:

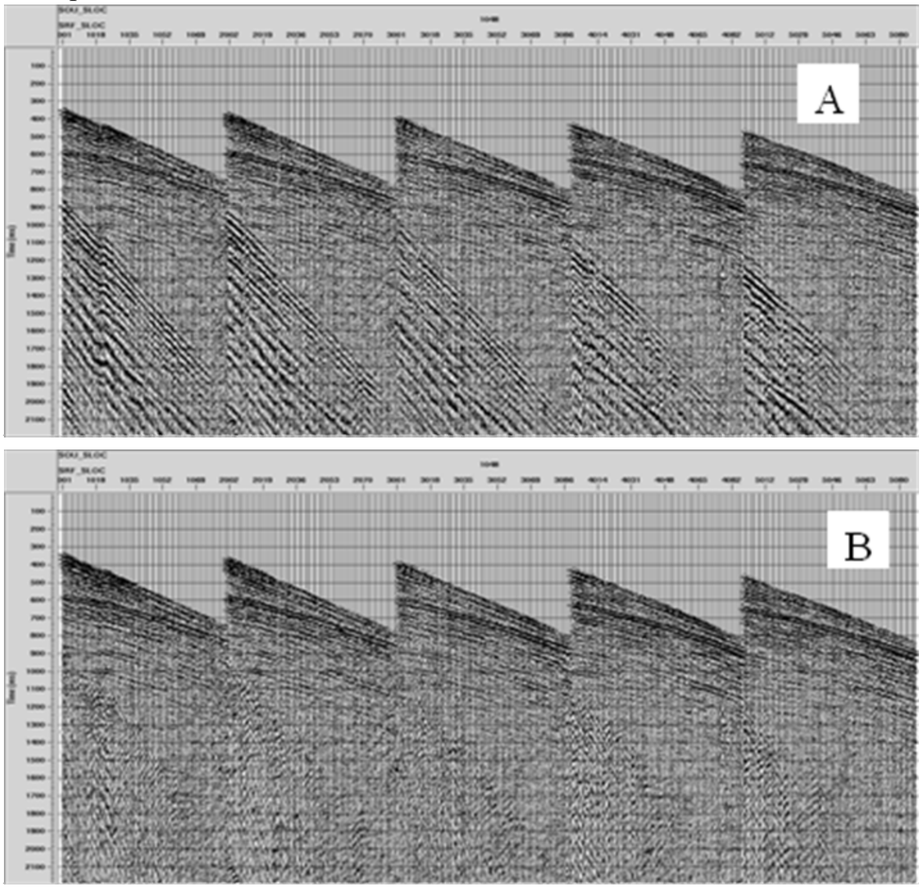


***Figure 2** Before (A) and after (B) removal of source generated filter by Radon filter. Top display ids weight drop data, bottom vibroseis data.*

All seismic volumes from 200 to 2010 are processed simultaneously using one processing flow (except for noise suppression) which was oriented on preserving reflection amplitudes. Processing of the data was performed with ProMax (Landmark, Halliburton) and RadExPro (DECO Geophysical) processing software systems. Different seismic vintages had to be cross-equalised For that purpose we used the following sequence (Shulakova et al, 2009):

1. Cross-correlation functions between each pair of traces from different cubes were calculated.
2. Amplitude balancing
3. Single matching filter for each pair of surveys was used to bring them to a common wavelet.

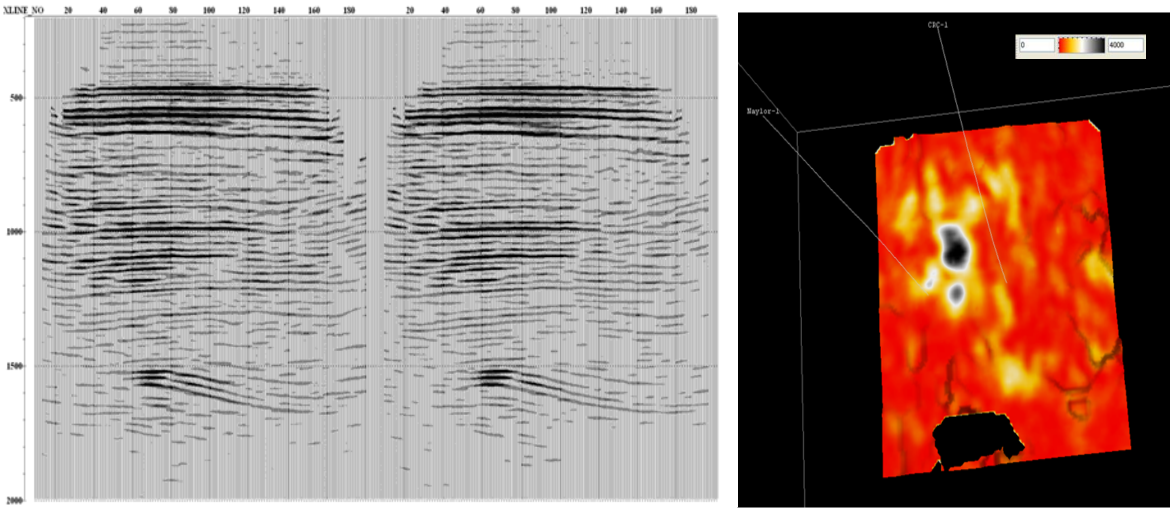
Discussion

An example of successful cross-equalisation and subsequent differencing is shown in Figure3. There, pre and post-CO2 injection volumes were subtracted, yielding a coherent difference image that was expected from numerical predictions (Urosevic et al. 2010). Comparing the data of Figures 3 (a and b) we can see that two data sets with vastly different noise pattern (Figure 1) were successfully cross-equalized. Similar results were obtained for three volumes recorded in 200, 2008 and 2009. The last volume recorded in January 2010 after injection of 66 Kt of CO2 is currently analysed and will be soon processed.

Cross-equalised volumes were used to investigate time-lapse effect for assurance monitoring during Phase I of CO_2 injection (Figure 3).

Conclusions

Around 66000 tonnes of CO2 have been injected into depleted gas field within the scope of CO2CRC



a) b) c)

Figure 3 *The result of data equalisation for 2008 -a and 2009 -b surveys and its difference energy –c.*

Otway projects. 4D seismic data were successfully acquired, processed and used to locate CO2 rich zone within the reservoir. A lot of efforts were made to study repeatability, it terms of its dependence on field acquisition and processing methodologies. This allowed us to achieve very high repeatability of land seismic TL3D measurements. High density and high fold surface seismic data enabled our processing methodology and cross-equalisation strategy to successfully perform.

Otway case study proves that on-shore time-lapse seismic is very valuable tool for monitoring of CO2 sequestration process, even in an extreme case which injection of CO2 into a deep, depleted gas reservoir as found in Otway basin.

Acknowledgment

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