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# Results From The Second Monitor DAS VSP At Quest CCS

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## Summary

The Quest CCS project uses time-lapse seismic methods to demonstrate conformance of the CO2 in the reservoir to modelled predictions. This paper outlines the results of the second monitor DAS VSP.

## Introduction

The Quest carbon capture and storage (CCS) project is a fully integrated CCS project developed as part of the Athabasca Oil Sands Project (AOSP), a joint venture between Canadian Natural Upgrading Limited, Chevron Canada Limited, and 1745844 Alberta Limited, and operated by Shell Canada Energy. CO2 is captured from the Scotford oil sands upgrader, located northeast of Edmonton, Canada, and transported by pipeline to the storage site. Over 1 million tonnes of CO2 per year is injected into the Basal Cambrian Sandstone (BCS), a saline aquifer located at a depth of about 2 km below ground surface (Tucker *et al*. 2016).

To demonstrate containment and conformance of the injected CO2, a Measurement, Monitoring and Verification (MMV) plan has been implemented. Time-lapse seismic methods are utilized for both containment and conformance monitoring. These methods currently include 3D surface seismic (3DSEIS), 2D surface seismic (2DSEIS) and 2D borehole VSP (2DVSP).

## The Role of time-lapse seismic in MMV at Quest

Time-lapse seismic is a key element of the Quest MMV Plan used to demonstrate conformance and containment of CO2 storage (Bourne *et al*. 2014). Specifically, time-lapse seismic images are they only demonstration of conformance of the CO2 behaviour in the reservoir to our expectations from reservoir models. The results provide an estimate of the rate and extent of CO2 plume growth and allow for a calibration of the dynamic reservoir models.

Time lapse seismic at Quest currently consist of eight multi-azimuth, walk-away VSPs acquired at each injection well location. The baseline DAS VSP was acquired in Q1 2015 (Mateeva *et al*. 2013), followed by the first monitor survey in 2016 and the second in 2017. All acquisition occurred in Q1 (winter in Canada) to allow for the same weather and ground conditions and therefore to maximize repeatability.

The time-lapse signal is interpreted as an image of the CO2 plume that has been injected into the pore space, displacing some of the brine in the saline aquifer, the BCS or Basal Cambrian Sandstone. The injected CO2 is more compressible and less dense than brine, and the p-wave velocity will be reduced where there is CO2. The time-lapse signal is interpreted by identifying slower travel time changes across the BCS and stronger reflections from the base of the BCS due to the increased impedance contrast with the underlying granitic basement.

## Time-lapse response of the CO2

The 2015 baseline and two monitor surveys were subject to the same processing workflow to preserve the time-lapse signal (Oropeza Bacci *et al* 2017). The results demonstrate a clear time-lapse signal present in the difference between the baseline and monitor data (Figure 1). The maximum distance illuminated by the VSP is approximately 800 meters away from each well.

The interpretation workflow utilized a suite of 4D attributes, including dRMS (Baseline_RMS – Monitor_RMS) and the RMS of the difference. These attributes were used to constrain the edge of the time-lapse anomaly, best described as an ellipsoid, as well as to understand the associated uncertainty in defining the anomaly (Figure 2). Interpretation uncertainty is derived from; for example, the difference between amplitude cut-offs defining the response, the variations between 4D attributes, and from the image projection due to the VSP geometry and offsets from the monitoring wells.

The main result is that an anomaly associated with the injected CO2 plume continues to be identified using time-lapse methods and is observed to be increasing in size.

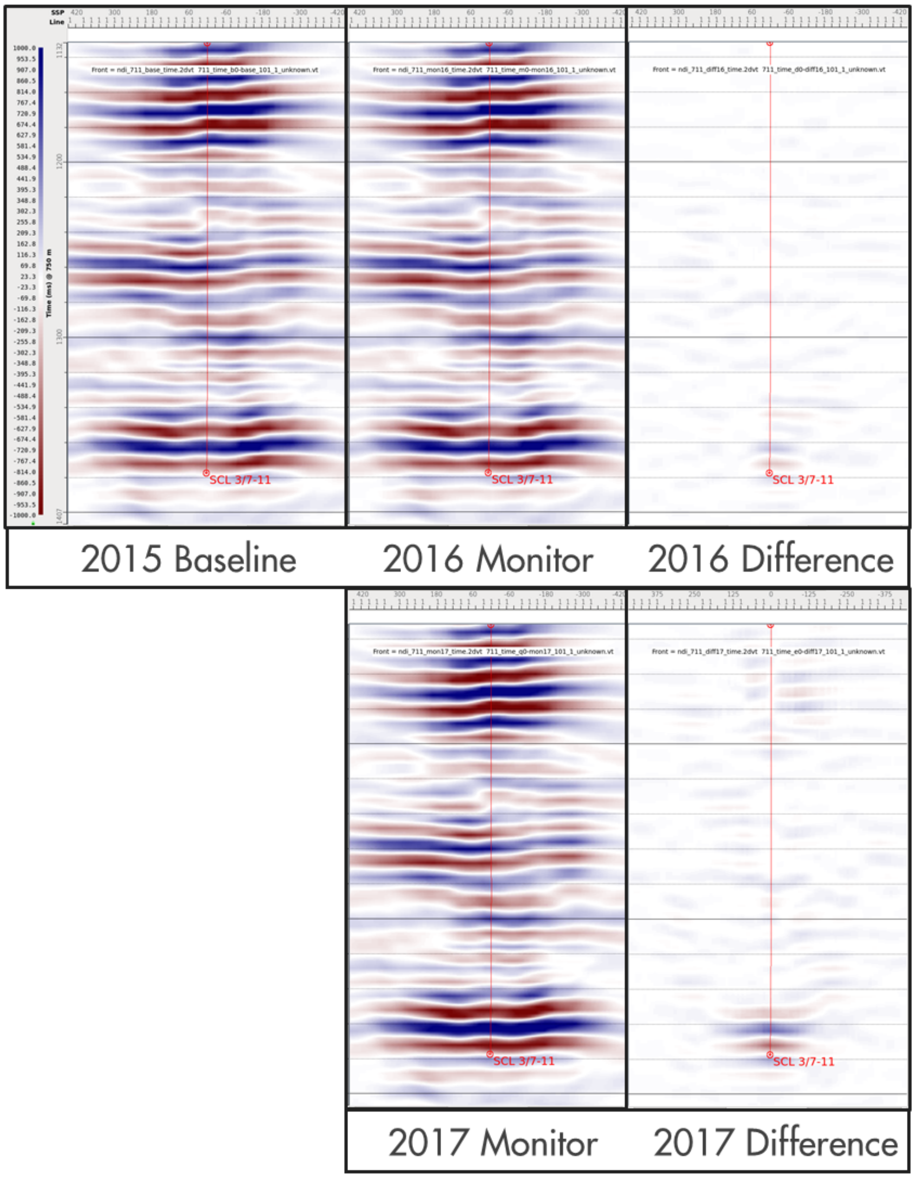


***Figure 1*** *Baseline, 2016 Monitor 1, 2017 Monitor 2 and each difference for injection well 7-11.*

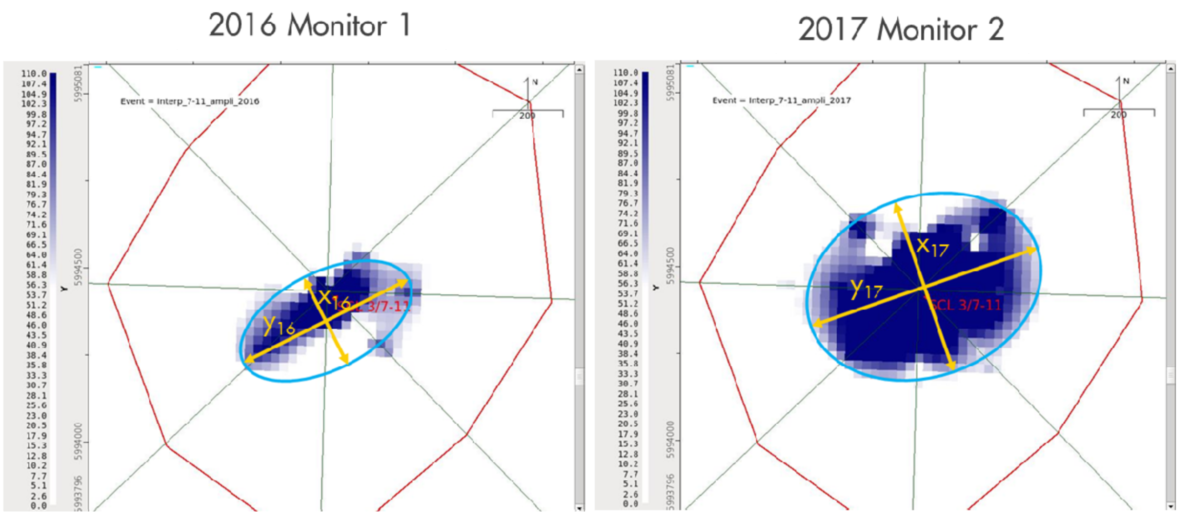


***Figure 2*** *Map view of interpolated amplitude differences for 2016 Monitor 1, 2017 Monitor 2 for injection well 7-11. X and Y arrows refer to ellipsoid approximations.*

**Conformance Monitoring**

Time lapse seismic is used to demonstrate conformance against our expectations, or models. The pre-injection Generation 4 (Gen-4) reservoir modelling report (Winkler 2011) predicted a range of uncertainties for the maximum plume lengths, where the plume edge is defined by 10m of reservoir at a 10% CO2 saturation (Figure 3). A theoretical minimum plume size was calculated assuming a cylindrical propagation of the CO2 in the entire BCS pore space using 100% CO2 saturations. When the interpreted dimensions of the CO2 extents (as calculated from the VSP) are plotted against these modelled predictions, the observation is that the size of the CO2 plumes are much smaller than what was predicted, and in fact closer to the theoretical minimum. The interpretation is that the reservoir is behaving better than expected, and that the displacement of brine by the CO2 is likely more effective than the pre-injection modelling predicted. This interpretation is supported by other operational measurements, such as pulse-neutron logging, temperature and injectivity data, and pressure fall-off tests.

This observation addresses the pre-injection conformance risk of storage efficiency – the CO2 plume is much smaller than predicted. The implication of this result is that the observed distribution of CO2 and pressure build-up inside the reservoir is well below the model-based predictions and provides additional confidence in the long-term effectiveness of CO2 storage. Consequently, this result also has an implication on the MMV Plan

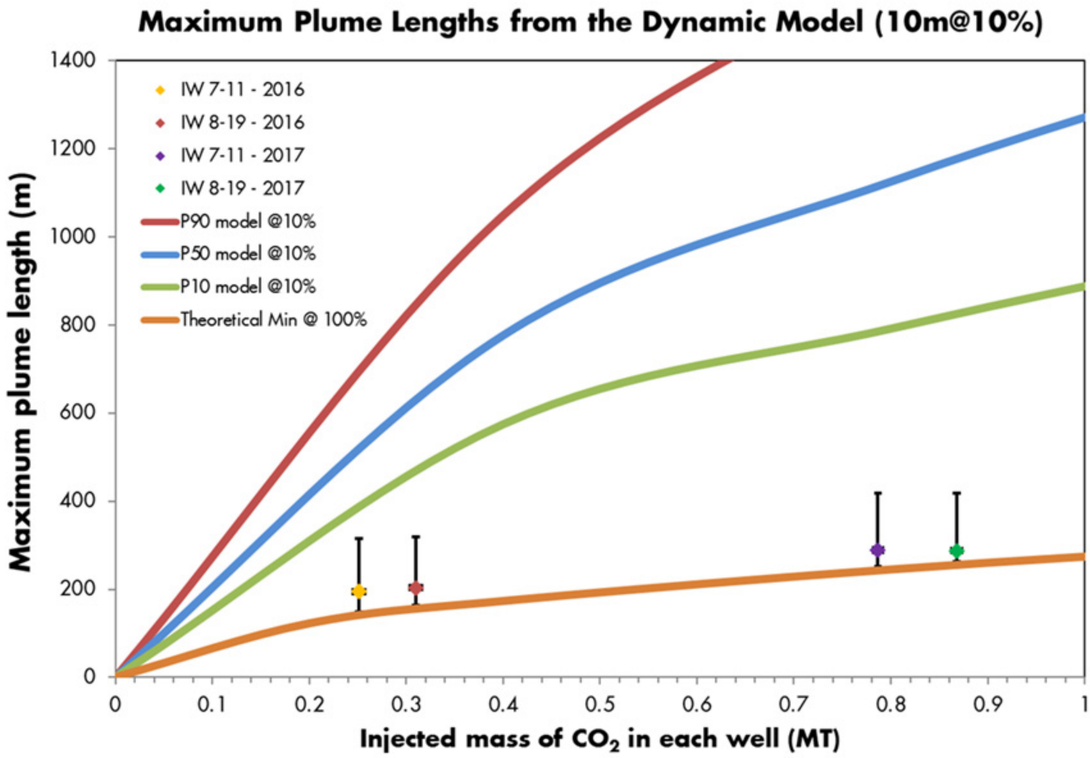


***Figure 3*** *Maximum plume length scenarios from the Gen 4 report and the theoretical minimum are compared to the measured plume size from the VSPs.*

**Conclusions**

The main outcome of the time-lapse seismic monitoring is to demonstrate that the measured size of the CO2 plumes is much smaller than the maximum plume lengths predicted from the Gen-4 modelling. The observation that the plume extent is closer to the theoretical minimum is another indication that the reservoir is behaving better than expected, and that the displacement of brine by the CO2 may be more effective than pre-injection modelling predicted.

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