ENHANCE ENERGY CLIVE MMV PLAN

APPENDICES J:

Geophysical Study of Cretaceous Porous Intervals at Clive in Response to CO_2 Emplacement

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Summary

A geophysical study was undertaken at Clive Alberta (Twp 40 Rge 24 W4M) to investigate the geophysical response of injecting miscible CO_2 into various stratigraphic intervals (Leduc reservoir, Manville, Viking, Belly River). Fluid replacement modelling was used to determine the theoretical response of adding varying concentrations of CO_2 as a function of total reservoir fluid at *InSitu* temperature and pressure. In the deeper reservoirs, as the effective pressure is such that the $C0_2$ remains in a liquid state, the slight change in bulk modulus (replacing a portion of one liquid with a different liquid with similar physical properties) results in a very slight (but measurable) change in the acoustic impedance. In the shallower horizons (Cretaceous), as the effective pressure on the fluids in the reservoir lessens and causes the CO_2 to transition to a gaseous state, the bulk modulus of the reservoir is reduced significantly, resulting in a more pronounced seismic response.

Introduction

Seismic response is determined by the physical and elastic properties of rocks and their constituent fluids. If the reservoir changes from a static to dynamic state, changes in pressure, temperature, and fluid content can cause measurable changes to the seismic response (Rabanni, Schmitt and Nycz, 2017). The magnitude and possibly even the causes of these changes can be measured through reservoir monitoring (well information, piezometers, thermocouples), or away from the wellbores by utilizing four dimensional seismic time lapse monitoring.

If the goal is determination of whether the dynamic reservoir seismic response is expected to change at all (as in the case of Clive), geophysical modelling can be a valuable tool. At Enhance Clive, an existing 3D survey serves as the baseline, and various concentrations of CO_2 fluid replacement modelling was conducted to determine at what concentration, and in what zones, CO_2 emplacement or injection would result in a change in the seismic response.

This study was undertaken to better understand under what conditions and in what zones CO_2 movement can be detected, and whether the existing Clive 3D survey could serve as a time lapse baseline. In the very unlikely event that during CO_2 injection fluid is transported through the geologic section, the goal of this exercise was to determine if seismic could detect CO_2 movement outside of the reservoir zone.

Methodology

Fluid replacement modelling was carried out using the IHS program GeoSyn and seismic synthetic modelling was undertaken in GeoSyn 2D. Gassman method of fluid replacement was utilized.

For the Leduc reservoir interval, values for the compressibility (inverse of bulk modulus) and density were obtained directly from the laboratory measured values from the CO_2 swelling study (2007). miscible mixtures of concentrations of 10.3, 19.9, 28.1, 35.9, and 45.4% concentrations of CO_2 and reservoir oil, as a function of effective pressure were used to model the geophysical response

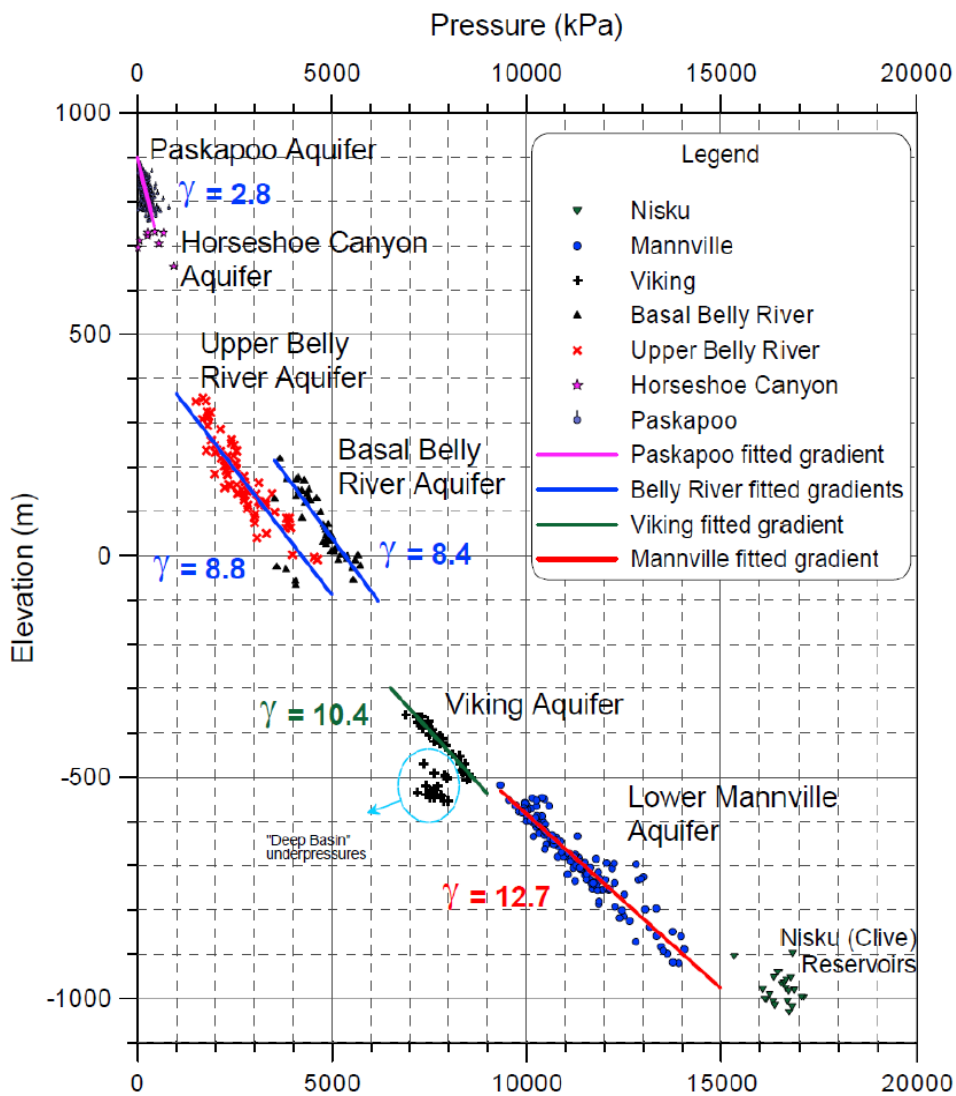
For the shallower zones, the compressibility was calculated using the following formula:

$$C_{g=\frac{1}{pressure}} - \left(\frac{1}{z}\left(\frac{\partial z}{\partial pressure}\right)\right)$$

Where:

Z= Compressibility factor

Cg= Compressibility of the CO_2 Pressure= effective pressure on the CO_2, as determined from AITF study completed in 2012 (graph below)

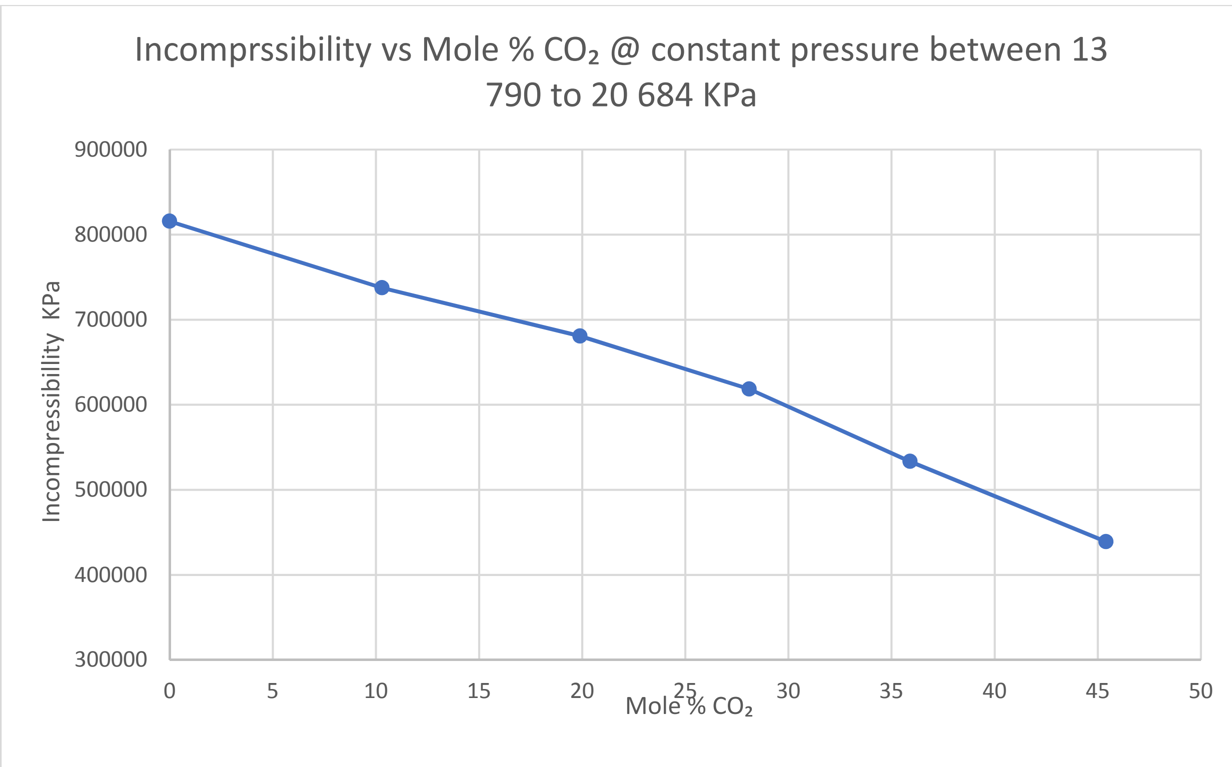


The above values are also dependent on temperature, which was determined from Thermocouple data for each zone, and was held static. CO_2 density was taken from measured values as a function of temperature and pressure.

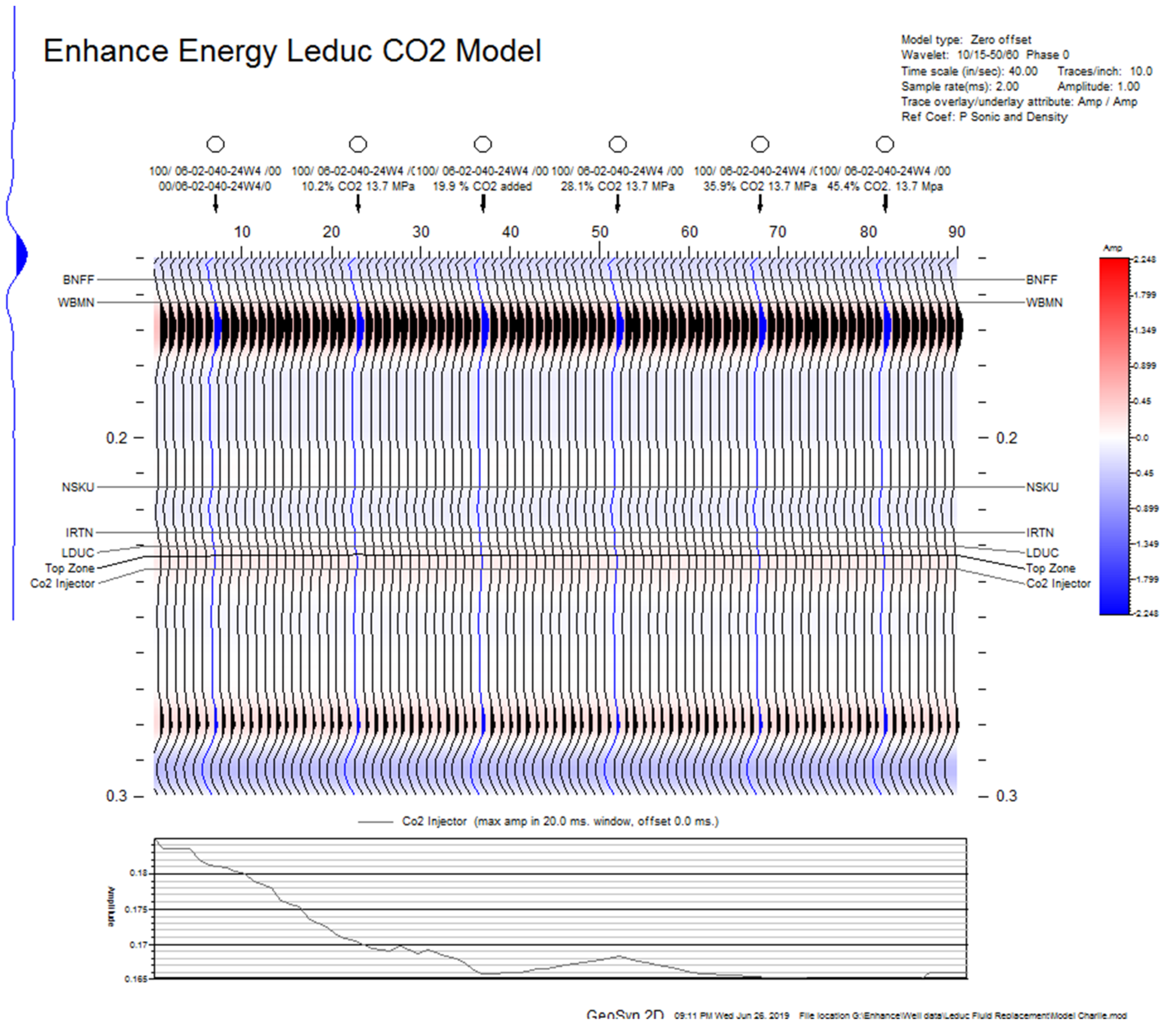
All modelling was carried out using the well logs from 100/06-24-040-24W4. Both sonic and density logs were used in the modelling

Results

In general, the calculated seismic response as a function of injected or emplaced CO_2 shows only a minor change as long as the injected CO_2 remains in a liquid state. Below is a graph showing the bulk modulus of the oil/CO_2 mixture in the Leduc from the Clive swelling study.

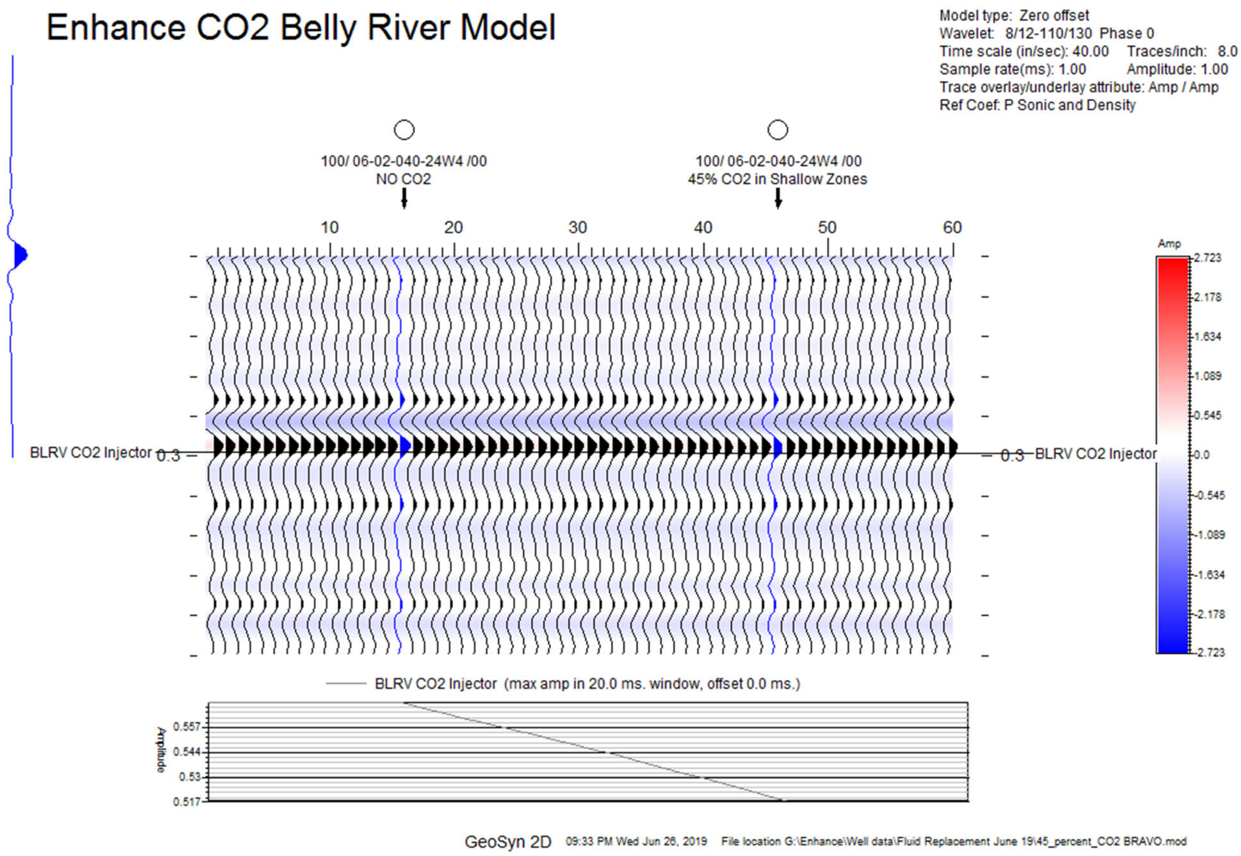


Although there is a decrease in the incompressibility (bulk modulus) of the fluid, it is not enough to cause a significant change in the acoustic impedance of the interval (density of the mixture increases only marginally from 760 kg/m3 with no CO_2 to 770 kg/m3 at 45.4% CO_2). Replacing the CO_2 miscible mixture in the all the pore spaces (20% prosody by volume), results in a very small change in acoustic impedance, and therefore seismic amplitude and character.



Geophysical model at reservoir level seismic frequency for the Leduc at Clive showing the response with no CO_2 (left most well) to reservoir fluid consisting of 45% CO_2. The difference in the maximum amplitude inside a 20ms window of the injector is only .02.

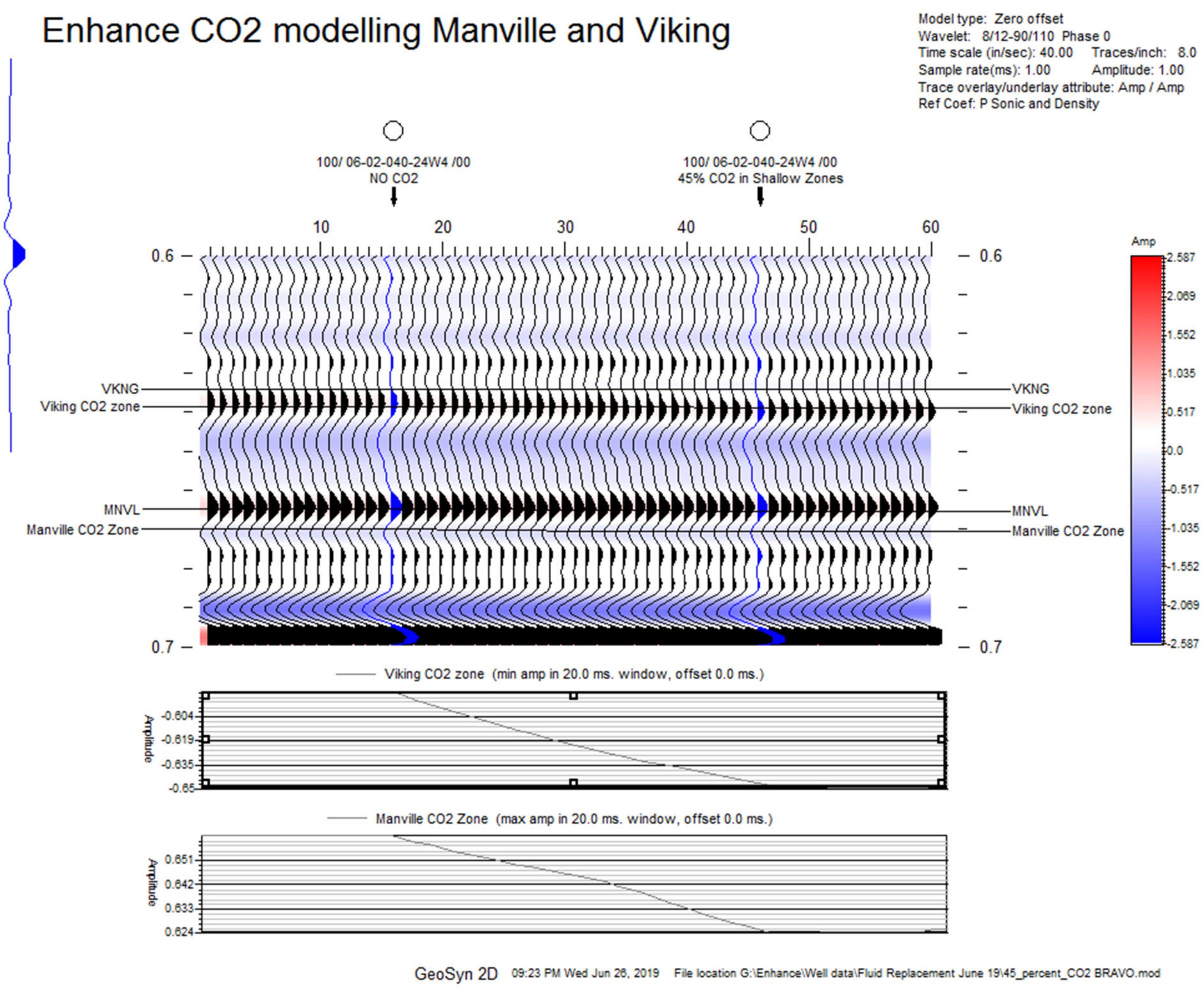
In the shallower horizons, as effective pressure is decreased, the bulk modulus decreases as does the density. As the CO_2 transitions to a gaseous state, these physical properties change more drastically. Below are geophysical models for porous zones in the Belly River, Viking and Manville porous intervals showing the zero offset geophysical P-wave response for the fluids in the reservoir transitioning from 0% to 45% CO_2.



The difference in the maximum amplitude in the Belly River sandstone resulting from injecting 45% CO_2 is .05.

Because geophysical response is determined by the change in acoustic properties of rocks and fluids relative to those surrounding it (at the scale of investigation, in this case frequency), the response of each zone to CO_2 injection will depend on the material above and below the CO_2 emplacement zone. As such, the response to CO_2 emplacement is non unique. For example, in the belly River at the 6-02-40-24 well, addition of CO_2 will result in a decrease on amplitude of the peak representing the Belly River sand. In the Viking, the addition of CO2 results in a noticeable character and amplitude change, whereas in the Manville, the change exists within the Manville Peak. It is worthwhile to note that in the Cretaceous zones, the magnitude of change (in whatever form it takes, as observed in the horizon graphs below the models) is at least double that of the change observed in the Leduc.

When analyzing time lapse seismic response, the changes are best quantified when comparing difference products (stacks, inversion data) between the baseline and monitor (Nycz, Yang and Schmitt 2016). Because the exiting Clive 3D was acquired before the injection of any CO_2, it could serve as a suitable baseline for any new seismic monitoring. Production of the Clive field that took place between the acquisition of the survey (2004) and the commencement of CO_2 injection would, due to the negligible difference in physical properties between the reservoir oil and water, cause no detectable difference in the seismic response in the Leduc, and no other zone would be effected as no other zone has ever produced, or been injected into. Therefore, any change in any new seismic compered to the baseline could be attributed to either CO_2 injection, or acquisition and processing differences between the baseline and monitor. By acquiring any new monitor with the same parameters, and processing both baseline and monitor simultaneously would minimize any artifact differences between baseline and monitor.



The reflectivity of the Viking is such that emplacement of CO_2 into the Viking sandstone to 45% concentration results in both a significant character and amplitude change (visualized by tracking the VKNG horizon in the model).

Conclusions

The modelling study shows the seismic response will be influenced by the injection or addition of CO_2 into various reservoirs. The degree of dependence is a function of temperature, pressure, porosity, and the % concentration of CO_2 in the reservoir, along with the acoustic properties of the rocks and fluids surrounding the zone affected by CO_2

Once the CO_2 transitions into a gaseous state, the seismic response of the CO_2 becomes more pronounced.

In terms of dynamic monitoring, it might be possible to monitor the CO_2 front in the Leduc through the acquisition of time lapse (4D) seismic, if this was desired information or deemed cost recoverable.

However, given the very small change in physical properties with CO_2 injection into the Leduc, dynamic monitoring of this zone would be extremely problematic as the differences between baseline and monitor would be very slight, and likely of lower magnitude than noise in the data and/or acquisition and processing differences between the baseline and monitor.

If the CO_2 breached the top of the injection reservoir and migrated up section, acquiring new 3D seismic (4D monitor) would be an effective method to augment engineering (well) data to monitor the movement of the CO_2 in these zones. The efficacy of this would be a function of, and improve with CO_2 moving to shallower sections of bedrock.

References

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