# Seismic modelling and monitoring of carbon storage in a sandstone aquifer

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## ABSTRACT

Carbon Management Canada in association with CREWES have invested in research projects that investigate the feasibility of injecting and monitoring relatively small amounts of $CO_2$ in sandstone aquifers in Alberta. In this case the target is a "shallow" sandstone layer of the Paskapoo Formation, southwest of Calgary. In order to evaluate the monitoring viability, Gassmann fluid substitution and 3D seismic modeling were undertaken. Synthetic seismograms were generated to assess changes given the injection of $CO_2$ in Lower Paskapoo sandstone. The resulting model attempts to represent the study site and its geology, therefore the seismic data acquired during 2010 field school was used as a guide. Using Norsar3D software, a pre-injection model and a post-injection scenario, which include the $CO_2$ plume, were obtained. The plume was estimated for a 3000 tonnes of $CO_2$, which is the expected injection amount after 3 years, and 50% $CO_2$ saturation. The plume size and shape was calculated taking using volumetric principles and the assumption of radial dispersion. From the resulting seismic volumes it is possible to appreciate a difference in seismic amplitude and time delay of the reflectors in the injection zone and underneath it. The changes caused by the presence of $CO_2$ are easily recognizable applying a subtraction of the post-injection model to the initial model.

## INTRODUCTION

The main purpose of this study was to generate a 3D geological model and subsequent seismic model that calculates the seismic response before and after $CO_2$ injection on the project land at the study site. The model attempts to characterize shallow geology, being based on the 2010 2D seismic line. The 3D survey only covers the expected injection zone to give a reasonable simulation of the seismic response after $CO_2$ injection. The study area is located in part of the eastern flank of the Rocky Mountains and is located 1.5 km southwest of the intersection of the Cowboy Trail and Highway 22X, approximately 10 kilometres west of Calgary's city limits (Figure 2). The injection site is located next to the Rothney Astrophysical Observatory (RAO). At the site, CREWES has undertaken several useful research projects in order to characterize this area, using multi-component seismic and vertical seismic profile (VSP) data (Lawton et al., 2008).

In order to select a suitable geological formation to storage $CO_2$, a main condition has to be covered: the presence of a permeable geological section overlain by an impermeable section (Havorka, 2008). The best example would be clean sandstone and shale trap. Giving that this project is conducted by Carbon Management Canada and the University of Calgary, the purpose of this injection would be the research and analysis of $CO_2$ sequestration in shallow storage formations, and therefore it was necessary to find a target meeting with these objectives. Based on these conditions the Basal Paskapoo Fm was selected as the injection target. In this project, the well used as reference in order to define the target properties is 12-33-21-2W5.

Figure 2 shows the full target zone from the Edmonton through to Paskapoo formations. Track 1 is the Gamma ray, track 2 is the P-wave velocity and track 3 is the density. The selected interval is from 750-785m in the well and is represented by a low gamma ray, high velocity and high density section which are typical of clean sandstone. Overlaying it, there is an approximate 10 m thickness with high gamma ray, low velocity and low density section interpreted as shale. This system of a permeable clean sandstone layer overlain by impermeable shale seams provides most of the fundamental conditions need for an injection target. The top of the Lower Paskapoo Fm is at a depth of 770m in the area of study and Edmonton Fm is at 805m.

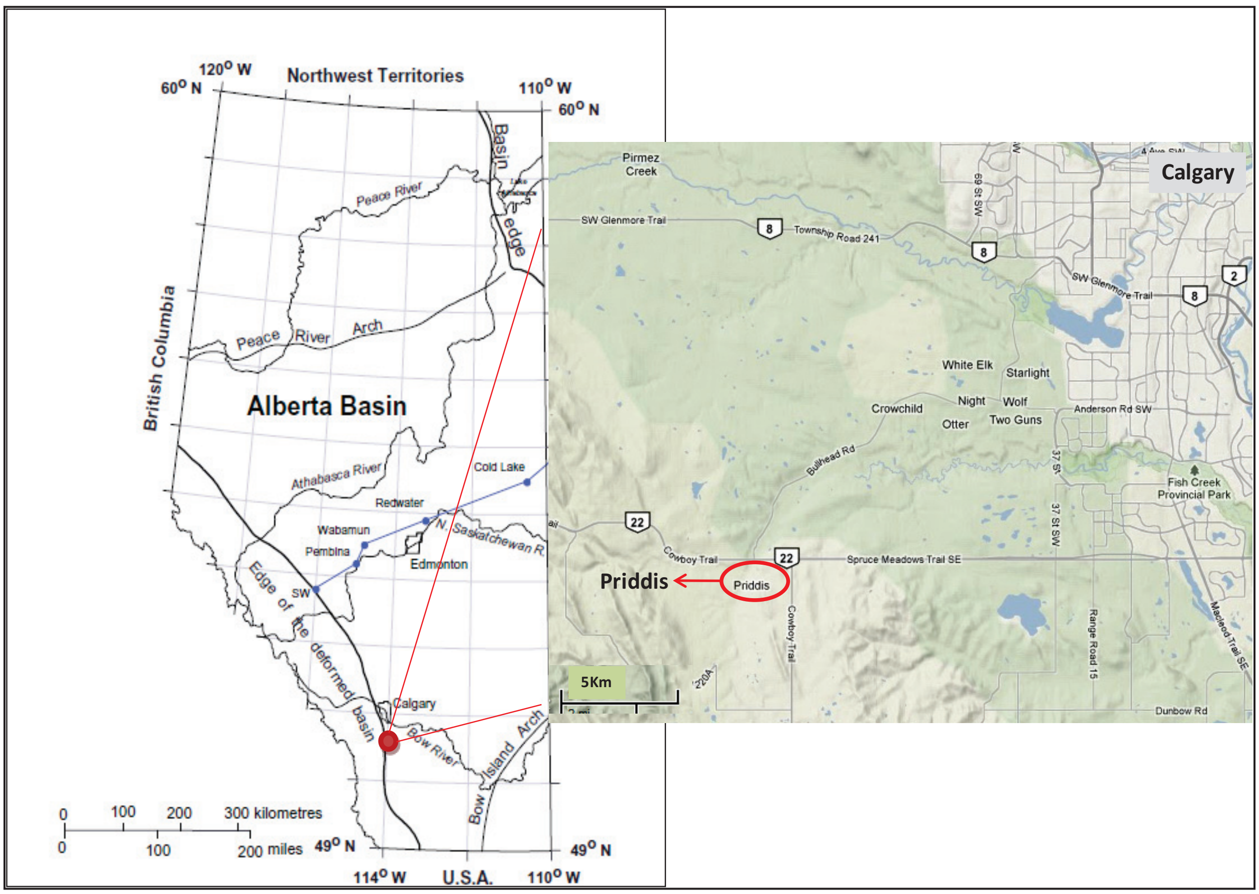



FIG. 1: Study location (red dot) (Modified from: Figure 3, Bachu et al., 2000) (http://www.baseloc.com/dls/#)

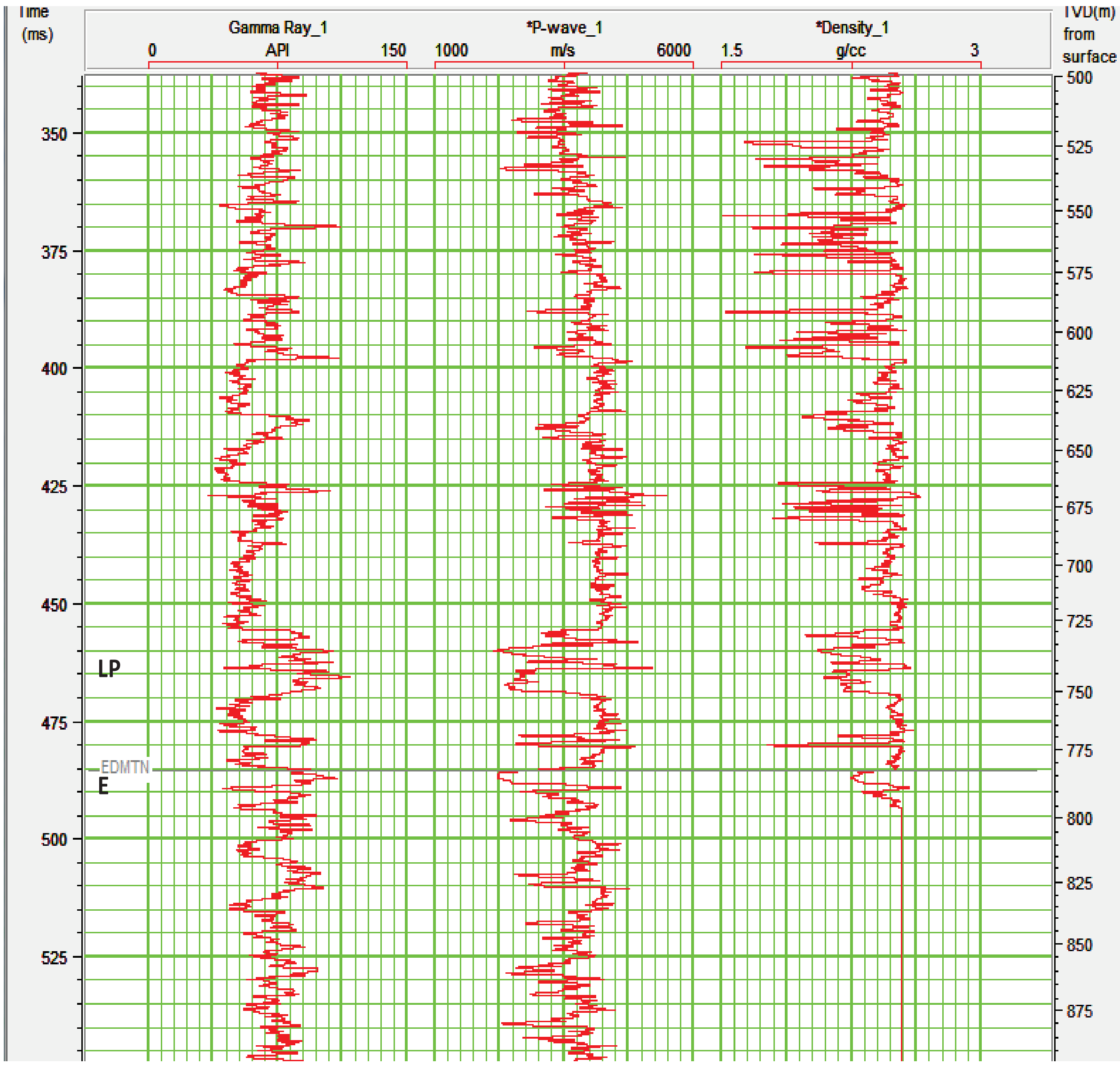



FIG. 2: Target zone (Lower Paskapoo [LP] –Edmonton [E] top) identified in the well 12-33-21-2W5: Gamma ray (track 1), density (track 2) and P-wave (track 3).

## GEOLOGICAL BACKGROUND

The study area is located at the eastern edge of the Rocky Mountain foothills in the triangle zone. This zone is between Jumping Pound and Wildcat Hills, Alberta (Slotboom et al., 1996). It is characterized by a blind thrust in the leading edge of the Rocky Mountain fold and thrust belt. In this zone the strata has wedged into the foreland succession with a blind frontal tip (Slotboom et al., 1996). The geometry of the area is defined by an amorphous flat base, beds and faults dipping toward the hinterland on the western side and some slight foreland dips on the eastern side, forming a triangle zone (Slotboom et al., 1996). Triangle zones are characterized by faults with opposite slip directions. They are related to a common lower detachment, so this faults and the detachment represent the triangle zone (Slotboom et al., 1996).

The section of Cretaceous and Tertiary strata was deposited by the end of the Laramide Orogeny phase and the beginning of the tectonic extension during the Tertiary (Dawson et al., 2008). These sediments came from a non-marine environment on the west, passing to marine towards the east. This section present four periods of clastic deposition composed by: Belly River, Horseshoe Canyon, Scollard and Paskapoo formations and four intervals of limited clastics composed by Pakowki, Bearpaw and Battle shales (Dawson et al., 2008).

The Paskapoo Formation represents the sequence of interest in this study. It is a Tertiary unit composed of continental to alluvial plain deposits of mudstone, siltstone and sandstone, with subordinate limestone and coal. Figure 3 shows the stratigraphic chart of sediments in the study area. The Paskapoo Fm. covers most of the Interior Plains area having, as correlative strata, Coalspur Formation out of the foothills towards the north (Dawson et. al, 2008). The sandstone grades to conglomerate in places, and bentonite beds are also present. The strata represent a foreland deposit of a siltstone- and mudstone-dominated fluvial system (Grasby et al., 2008).

The Paskapoo Fm. constitutes an important ground water reservoir target, having qualities that make that possible because of the occurrence of high-porosity coarse-grained sandstone channels (Grasby et al., 2008). The basal Haynes Member and western portion of the Paskpaoo Formation have higher sandstone volumes than other portions of the system (Grasby et al., 2008). Paskapoo is the youngest bed rock deposits in the Western Canada Sedimentary Basin having from 0 to 800m of thickness with a thinner section in the eastern part (Grasby et al., 2008). The deposits are distributed in an asymmetric foreland basin developed between the deforming mountain front and the adjacent craton due to the western thrusting of the Rocky Mountains (Grasby et al., 2008). The main source of sediments was the emerging mountains of Palaeozoic-Mesozoic rocks. The strata are composed of greenish sandy siltstone and mudstone, with light grey, thick-bedded sandstone deposited in non-marine environments (Grasby et al., 2008). A plain zone where the strata are dipping westward, forming a homoclinal wedge into Alberta syncline, is called Paskapoo Sandstone, which has the most representative sandstone channels. Outside this sandy zone, the formation is composed for more than 50% of siltstone and mudstone (Grasby et al., 2008).

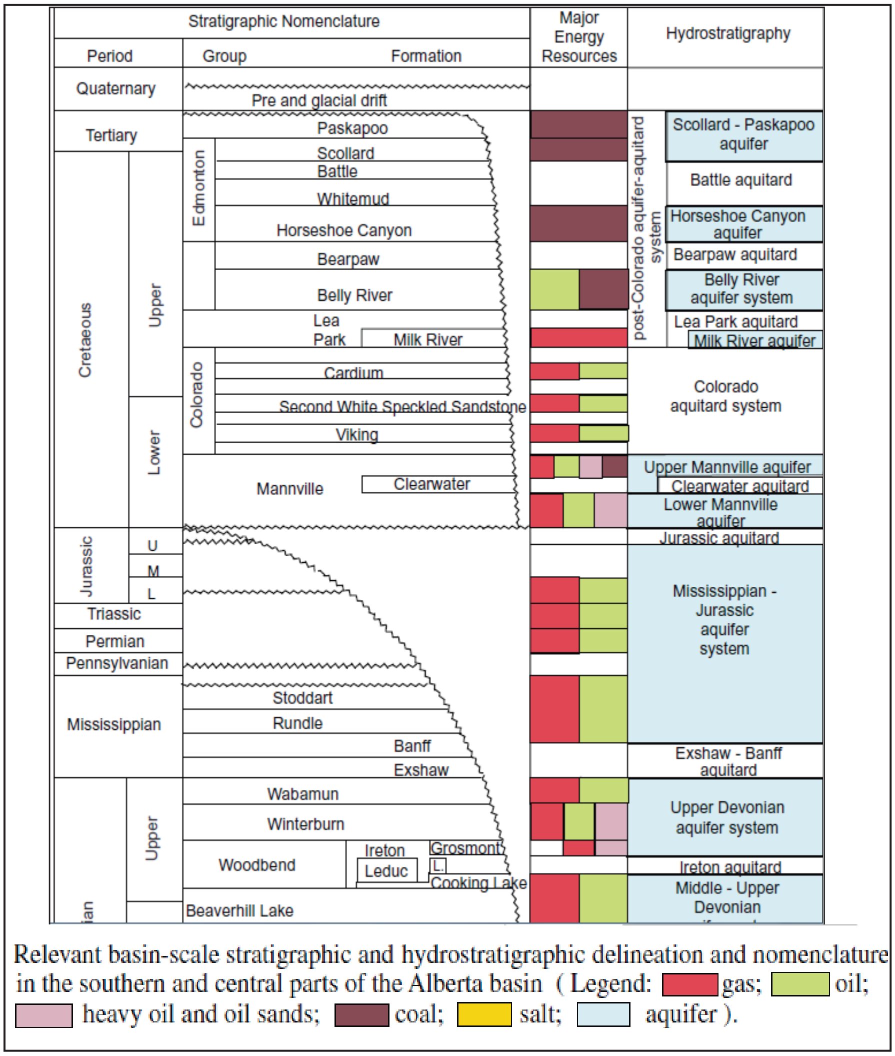



FIG. 3: Stratigraphic sequence of the southern Alberta basin, including hydrological and fluid information (from Dawson et al., 2008).

## SEISMIC MODELLING

### Local geological model

A 3D geological model was generated using Norsar3D with the goal of producing a detailed scenario of the injection zone using as a guide the 2010 2D seismic line and knowing the flat crossline tendency from the 2010 3D survey. The result was a 2.5 km E-W (towards the foothills) and 1 km N-S 3D model. During the design process the geological background, the well information and seismic data was taken into consideration. The methods applied in the 3D model generation included several steps:

*Interpretation of the main formation tops using Kingdom Suite Software*

The interpretation is based on the work of Isaac and Lawton (2010). The interpreted horizons are shown in Figure 4: Middle Paskapoo A sand (MPA), Middle Paskapoo B sand (MPB), Lower Paskapoo sand (LP), Edmonton Group (E), Upper Detachment (UD), Lower Detachment (LD), Belly River (BR), Milk River (MR), Cardium (C) and

Mississippian (M). In addition, a reference horizon named "Seal" was selected from the well logs as the next significant shale section on top of Lower Paskappoo in case of needing a secondary closure for the $CO_2$.

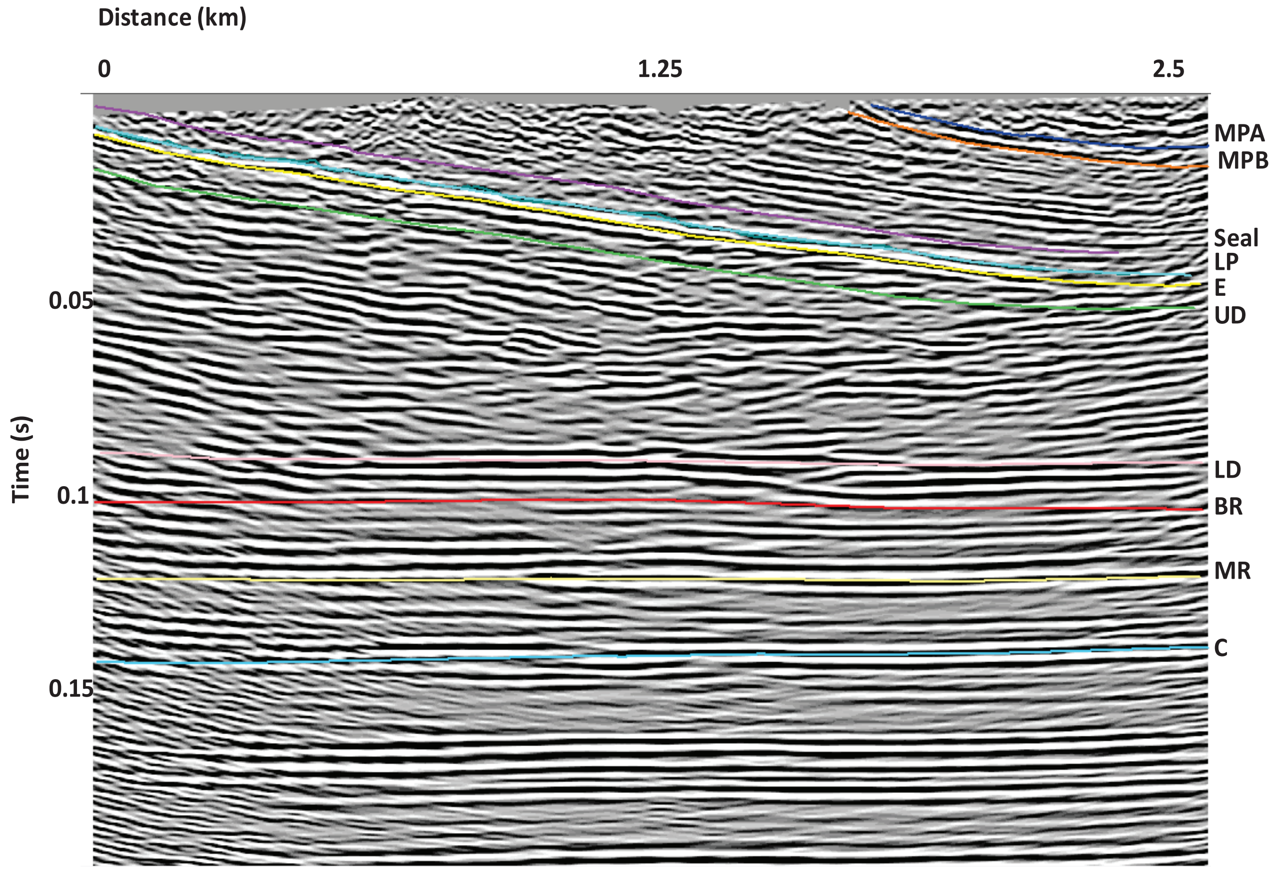



FIG. 4: 2010 2D seismic section with the interpretation of: Middle Paskapoo A sand (MPA), Middle Paskapoo B sand (MPB), Seal, Lower Paskapoo sand (LP), Edmonton Group (E), Upper Detachment (UD), Lower Detachment (LD), Belly River (BR), Milk River (MR), Cardium (C).

*Generation of grid maps from the 2D interpretation*

The grids were obtained from the interpreted horizons by using Kingdom Suite grid module and specifying the size of 2.5x1 km. In order to get a geological model it is necessary to obtain a representation on depth of the interpreted seismic. Moreover, it was estimated the average velocity between each Formation top taking the sonic log from well 12-33. Using these values, each of the time grids were multiplied by its corresponding average velocity. Finally it was obtained the depth representation of the horizons. Figure 5 is one of the map examples generated from LP. The combination of all this grids would be the final 3D model shown in Figure 6. The grids where exported as ASCII files.

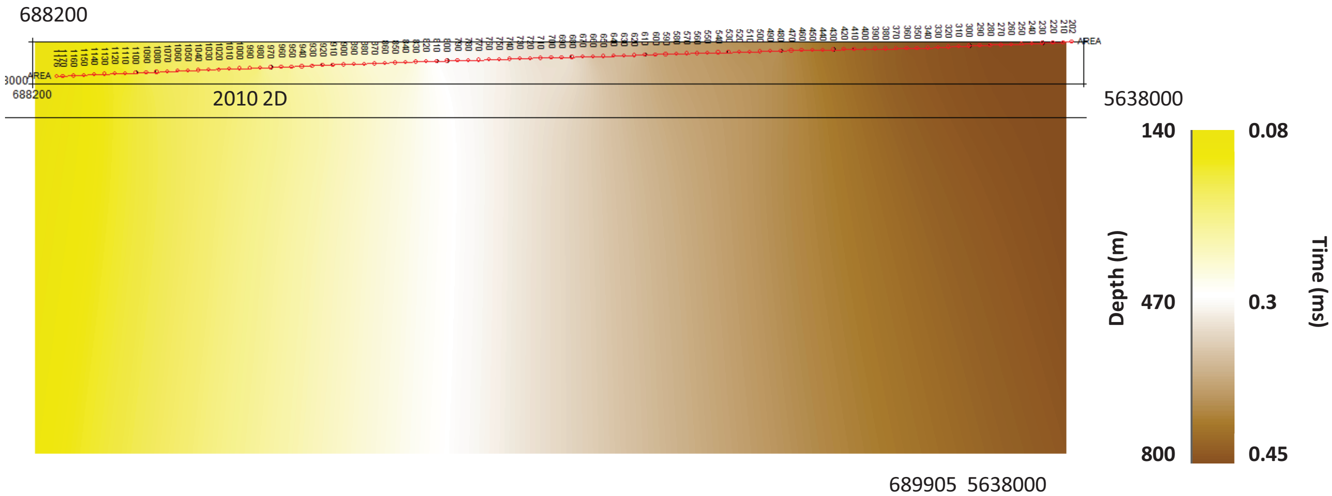



FIG. 5: Grid map generated from the LP horizon. The scale is shown in depth and time.

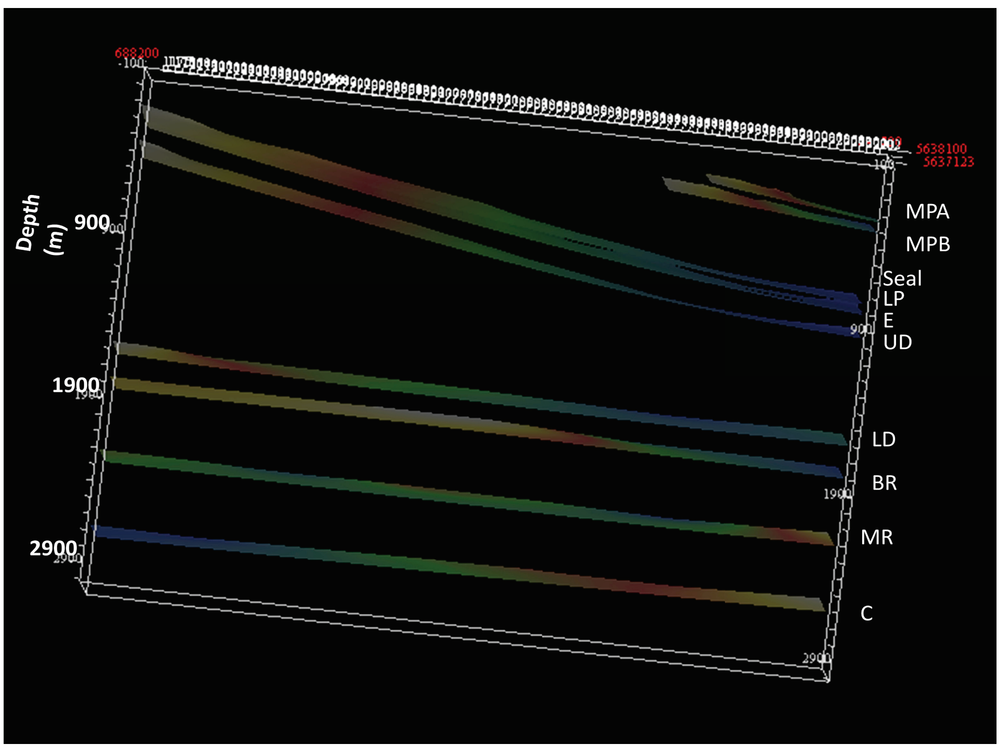



FIG. 6: 3D view of the depth grids for ten horizons of the model.

*Create a project in Norsar3D and import the depth grids*

The grids were used as interfaces in the generation of the geological model. Figure 7 is the result from Model Builder module from Norsar3D, which was used in the further seismic modelling. The density and P-wave velocity values of each of the layers were obtained from well information and are shown in Table 1. Layer 1, 2 and 3 values were averaged in order to avoid the distorting effect of the low densities and low velocities of the first two layers.

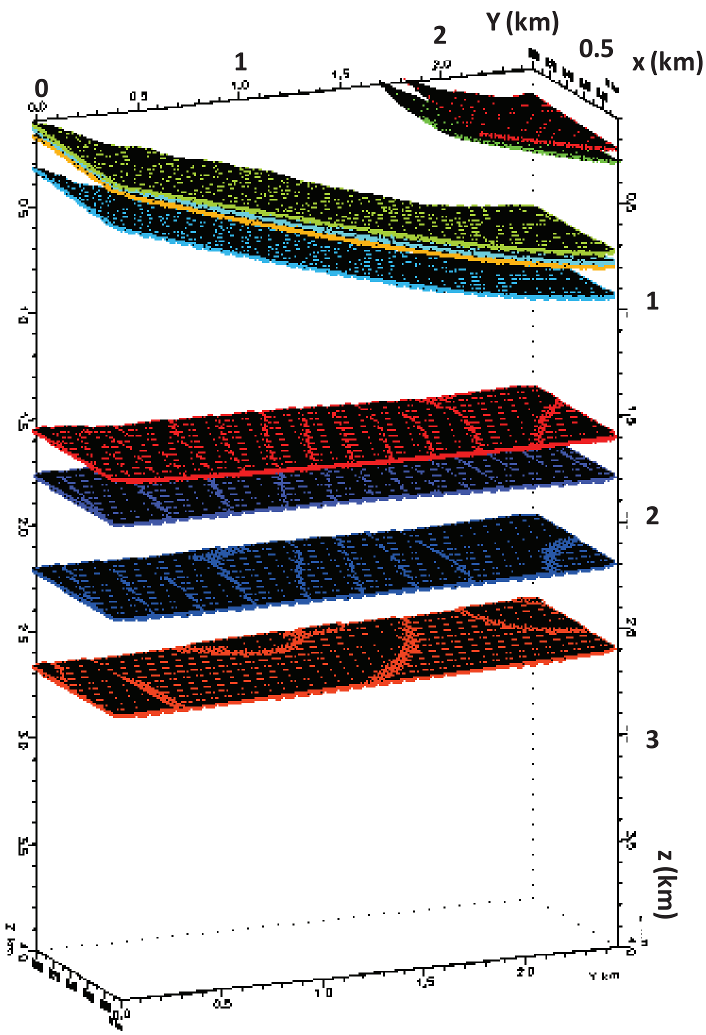



FIG. 7: 3D model in Norsar3D obtained after importing the horizon grids.

| Layer | Interfaces | Density ($kg/m^3$) | $V_p$ (km/s) |
|---|---|---|---|
| 1 | Surface-MPA | 2300 | 3.7 |
| 2 | MPA-MPB | 2300 | 3.7 |
| 3 | MPB-Seal | 2300 | 3.7 |
| 4 | Seal-LP | 2400 | 3.9 |
| 5 | LP-ED | 2500 | 4.1 |
| 6 | ED-UD | 2400 | 3.6 |
| 7 | UD-LD | 1700 | 3.3 |
| 8 | LD-BR | 2300 | 3.8 |
| 9 | BR-MR | 1900 | 4 |
| 10 | MR-C | 2000 | 4.2 |
| 11 | C | 2300 | 4.4 |

Table 1: Density and P-wave velocity values for each of the layers in the model

## Simulated $CO_2$ plume

There are several techniques that can be applied in order to estimate the amount of $CO_2$ trapped in geological formations, based on similar methods used in oil and gas and ground water reservoirs (Frailey, 2009). They are two fundamental types: static and dynamic. The first approach requires rock and fluid properties while the second method requires information about active injection, injection volumes and reservoir pressure (Frailey, 2009). The technique selected in this project is static, specifically the volumetric method which is based in the following formula:

$$G_{CO2} = \mathrm{Ah\phi E} \quad (1)$$

where $G_{CO2}$ is the $CO_2$ volume, A is the area, h is the thickness, ϕ is the porosity and E is the efficiency which can be equated to average saturation as well. $G_{CO2}$ is given by:

$$\mathrm{G_{CO2}} = \mathrm{V} = \mathrm{m}/\rho \quad (2)$$

where m is the mass of $CO_2$ and ρ is the density under the specific conditions of temperature and pressure.

The geometry of the expansion considered in this project is a disk or cylindrical dispersion with the same radio along the layer thickness, having an area of:

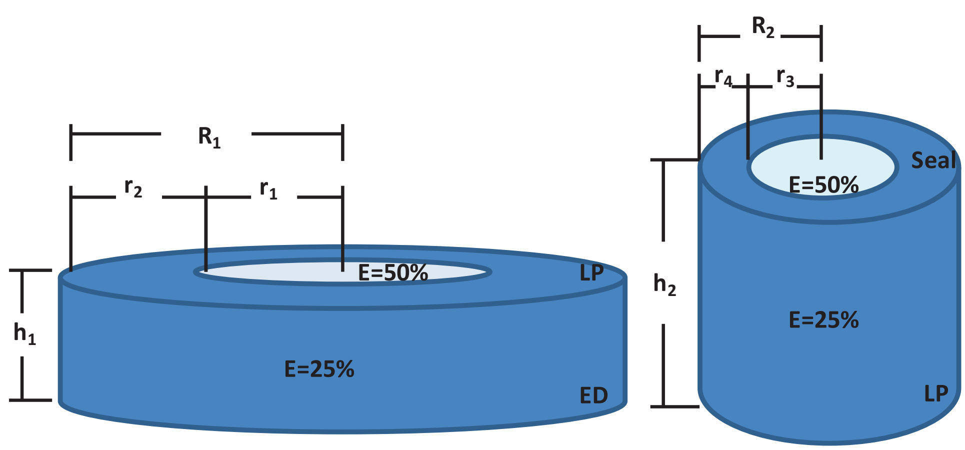
$$A = \pi r^2 \quad (3)$$

where r is the radius of the disk of $CO_2$ expansion. This radius is the value needed in order to generate the simulated plume. By rearranging the volumetric formula and introducing the previous expression, r is obtained using the following equation:

$$r = \sqrt{G_{CO2}/\pi h \phi E} \quad (4)$$

The simulated amount of $CO_2$ was 3000 tonnes, considered to be the maximum injected mass after 3 years of injection. In the 3D case it is possible recreate the disk shape. Furthermore, other complexities were added such as: the consideration of a non 100% effective seal on top of Lower Paskapoo having leakage of the fluid trough the next layer and the presence of a transition zone with lower saturation surrounding the inside dispersion disk.

In this model was also assumed that 25% of the $CO_2$ would leak upwards to the next surface. That next surface was selected from log information and it is 60 m above LP. This is the only added interface that doesn't represent a Formation top. Thus, the final model is: 75% of the total mass would remain trapped between the top of the Edmonton Fm and the top of the Lower Paskapoo Fm.,, and the rest between Lower Paskapoo and the new "Seal" layer. Complementing this, it was assume that, in both case (upper and lower cylinder), 90% of the $CO_2$ represent 50% saturation in the storage formation porous space, while 10% would be part of an outer disk with 25% saturation in a transition zone. In total it was created a model composed of four disks illustrated in Figure 8.




a) b)

FIG. 8: Representation of the plume geometry. (a) represents the plume injected between LP and ED and (b) represents the leaked 25% of the CO2 injected and trap between LP and the "Seal".

The first two disks were located between Edmonton and Lower Paskapoo formations having: a thickness: h = 35 m, porosity $\phi$ = 9% and a $CO_2$ density under the LP conditions $\rho CO_2$ = 340 kg/m$^3$. The efficiency would be considered as the saturation of $CO_2$, E = 50% for inner disk and E = 25% for outer disk. Between E and LP tops, 2250 tonnes remained. The final volume in this first section is thus:

$$V = \frac{2{,}250{,}000 \text{ kg}}{340 \text{ kg/m}^3}$$

$$V_{LP-ED} = 6{,}617.64 \text{ m}^3$$

90% of this volume remains in the first dispersion disk:

$$V_{r1} = 6{,}617.64 \text{ m}^3\text{x}0.9\text{= }5955.876\text{m}^3$$

and the other 10% would represent the outer disk with a volume of:

$$V_{r2} = 6{,}617.64 \text{ m}^3\text{x}0.01\text{= }661.76\text{m}^3$$

Having all this elements it is possible to calculate the radii of both disks, first the inners disk "$r_1$":

$$r_1 = \sqrt{\frac{V_{LP-ED}}{h\phi E_{50\%}\pi}}$$

$$r_1 = \sqrt{\frac{5955.87m^2}{4.945m}}$$

giving as a result $r_1$=34.704m or approximated 35m. Following the same process for the second disk, "$r_2$" is:

$$r_2 = \sqrt{\frac{V_{LP-ED}}{h\phi E_{25\%}\pi}}$$

$$r_2 = \sqrt{\frac{661.76m^2}{0.7875m}}$$

with a final $r_2$=28.9m or approximated 30m, resulting in a outer radio of $R_1$=65m.

The same procedure was followed for the second two disks, located between Lower Paskapoo top and the seal layer having: thickness h = 60 m, porosity $\phi$ = 15% and $CO_2$ density under the LP conditions $\rho CO_2$ = 323 kg/m$^3$. The considerations regarding saturation would be the same, E = 50% for inner disk and E = 25% for outer disk. In this second disks group there is 25% of the $CO_2$ resulting in 750 tonnes between LP and the Seal. The volume in this section is:

$$V = \frac{750{,}000 \text{ kg}}{323 \text{ kg/m}^3}$$

$$V_{seal-LP} = 2{,}321.98 \text{ m}^3$$

90% of this volume remains in the first dispersion disk:

$$V_{r3} = 2.321{,}98 \text{ m}^3\text{x}0.9 = 2{,}089.78\text{m}^3$$

The other 10% would represent the outer disk with a volume of:

$$V_{r4} = 2.321{,}98\text{m}^3\text{x}0.01 = 232.19\text{m}^3$$

Having all this elements it is possible to calculate the radio of both disks, first the inners disk "$r_3$":

$$r_3 = \sqrt{\frac{V_{seal-LP}}{h\phi E_{50\%}\pi}}$$

$$r_3 = \sqrt{\frac{2089.78m^2}{4.5m}}$$

giving as a result $r_3$=21.55 m or approximated 22 m. Following the same process for the second disk, "$r_4$" is:

$$r_4 = \sqrt{\frac{V_{seal-LP}}{h\phi E_{25\%}\pi}}$$

$$r_4 = \sqrt{\frac{232.19m^3}{2.25m}}$$

with a final $r_4$ = 10.16m or approximated 10m, resulting in a outer radio of $r_2$ = 32m.

## Model after $CO_2$ injection

After defining the shape and size of the $CO_2$ plume it was possible to design it in Norsar3D and make it part of the geological model, representing the post-injection scenario. The same model previously explained was applied and now the $CO_2$ plume would be a new set of interfaces that constitutes individual blocks with the respective velocity and density values obtained after applying Gassmann fluid substitution. Fluid substitution was perform over both lithological sections for a saturation of 50% and 25% $CO_2$ following the same procedure explained in Vera and Lawton (2010). Table 2 summarize the parameters for each of the disks.

| Disk | Density (kg/m$^3$) | $V_p$ (km/s) |
|---|---|---|
| LP-ED inner (E=50%) | 2480 | 3.98 |
| LP-ED outer (E=25%) | 2490 | 3.89 |
| Seal-LP inner (E=50%) | 2350 | 3.75 |
| Seal-LP outer (E=25%) | 2380 | 3.65 |

Table 2: Density and P-wave velocity values for the different disks of the $CO_2$ plume.

These density and P-wave velocity values were added to the property selection in the post injection model. Figure 9 is a cross section with the different property blocks, where the different parts of the disk model are included. Figure 10 shows the final plume modeled in Norsar3D; the cylinder walls represent the interfaces separating the changes in properties depending on the $CO_2$ saturation.

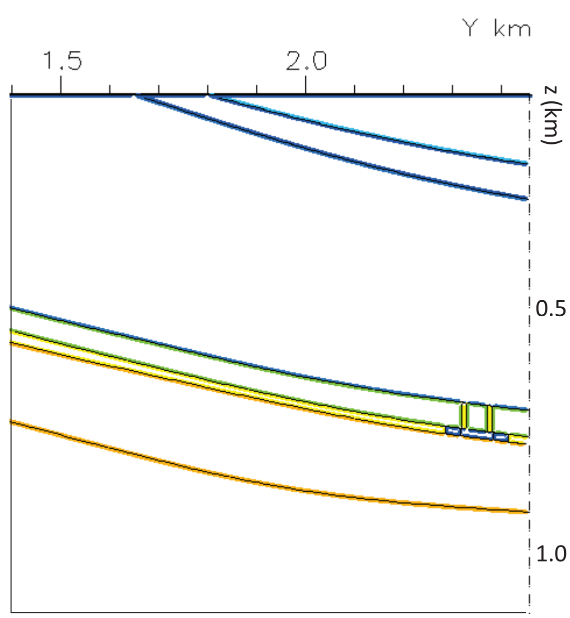



FIG. 9 Cross section view of the model showing in color the different block limits. In this model it is possible to see the different components of the disk model.

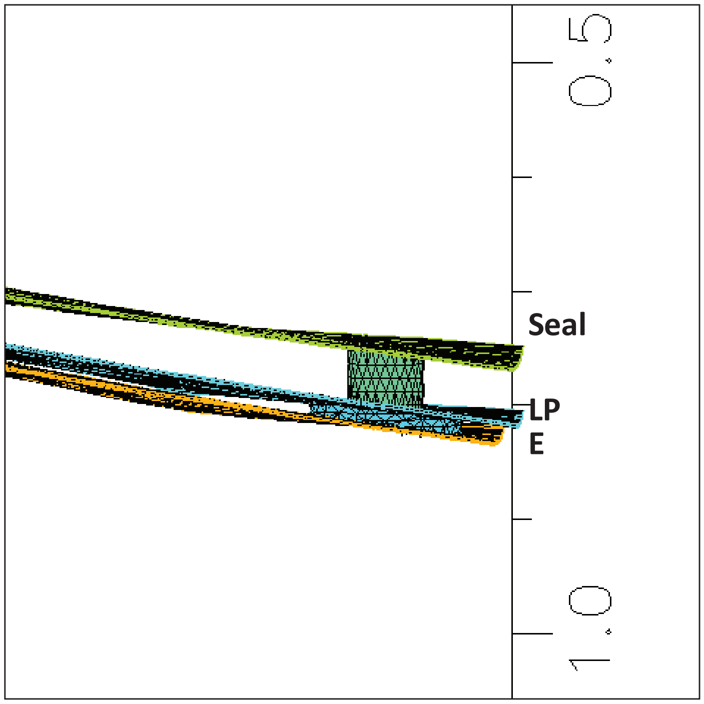



FIG 10: 3D view of the plume. The first cylinder is between Lower Paskapoo and Edmonton and the second between Seal and Lower Paskapoo.

### 3D Seismic modelling

A seismic survey was designed to image with precision Paskapoo and the plume. It is important to notice that even when the geological model extends about 2.5 km the survey will be 700x600 simulating the acquisition for the $CO_2$ monitoring in the area of injection. The survey is composed by: seven receiver lines in an east-west direction and fifteen shot lines oriented north-south. The spacing between shot lines is 100m and receiver lines 50m, with shot points at every 20m and geophones at every 10m (see Figure 11).

Having the model and seismic survey, Norsar's common shot wavefront tracer was applied as shown in Figure 12. The raytracing was undertaken for the 480 shots having the total 511 receivers live for each shot. The same process was implemented over the initial model and repeated after injection and the resulting reflectivity events were used in the synthetic seismogram generation. The synthetic seismogram is the result of the convolution between the reflectivity series with a selected wavelet in this case a zero-phase Ricker with 70 Hz frequency, which allows the resolution of the target zone. The sample interval is 1 ms and record length is from 0 to 2 sec.

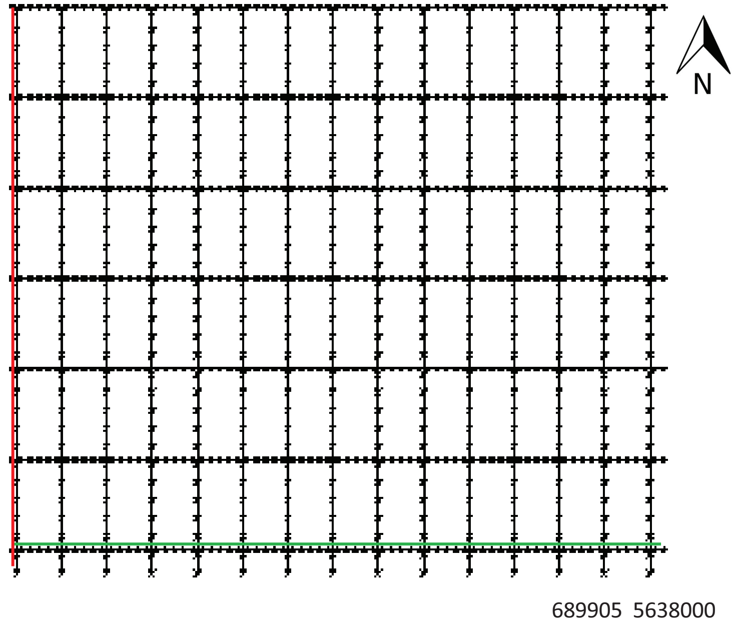



FIG. 11: The layout for the 3D seismic model. Receiver lines direction in green and shot lines are in red.

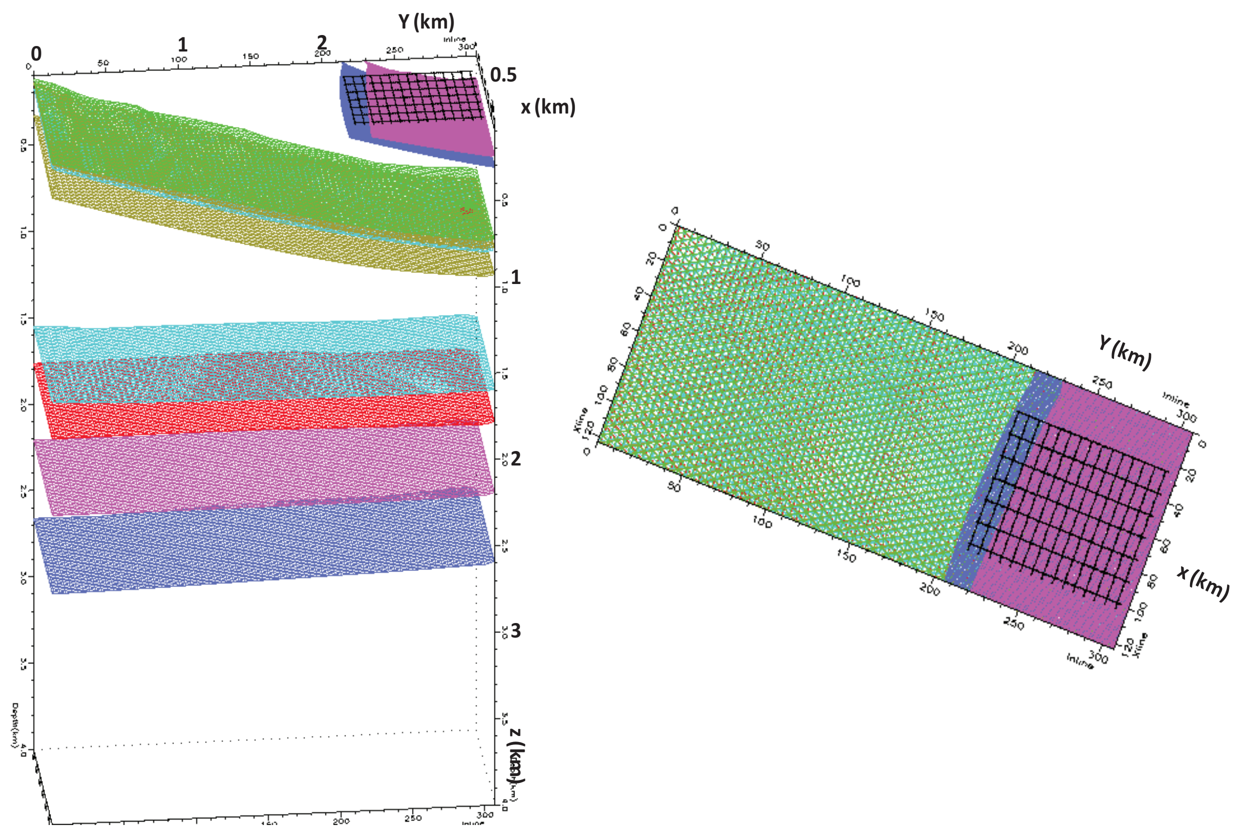



Figure 12: Geological model with the survey location.

## Data processing

The seismic file in SEG-Y format generated from Norsar3D was used as input data for the processing. Promax software was used following a basic flow. Figure 13 is an example shot gather showing the seven inlines with 73 receivers. It is possible to identify eight of ten reflectors from the model; the first two layers were intentionally attenuated by putting the same velocity and density. The first step for processing is the 3D geometry assignment and binning of the data imported from Norsar3D. The distance between receivers is 10 meter and between shots 20m, with CDP bins of 5x10m having an average fold of 60 and a maximum of 84, located in the center of the survey as shown in Figure 14.

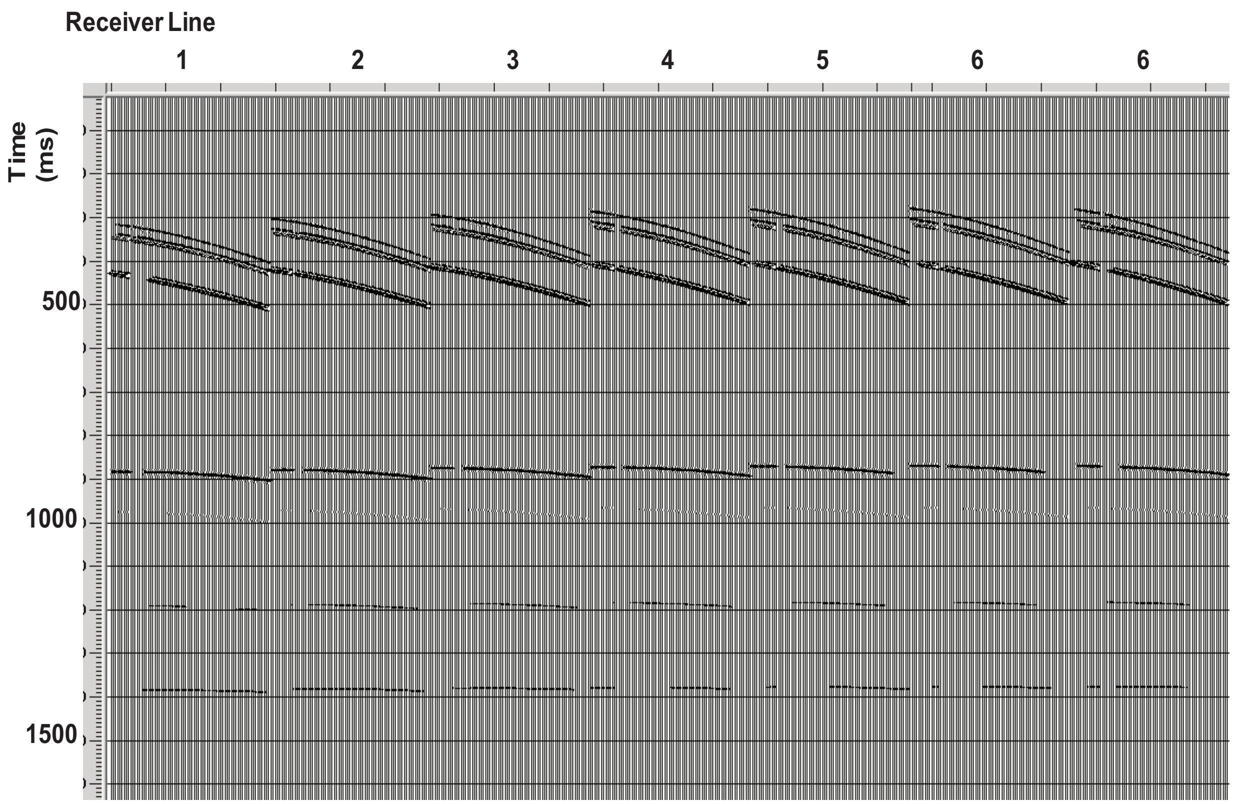



FIG. 13: An example shot gather showing the seven receiver lines.

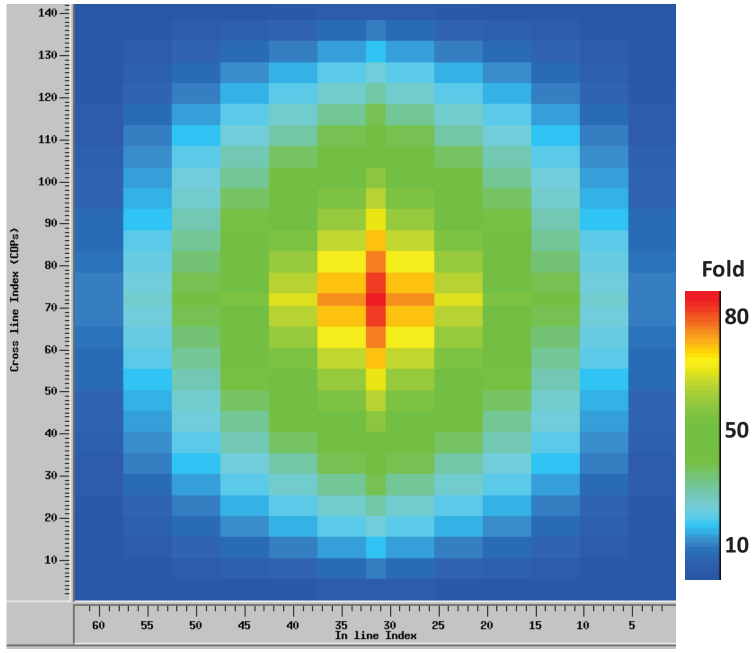



FIG. 14: CDP fold of the 3D model

This model does not include topography, a weathering layer or noise, so it was not necessary to apply any static correction or noise attenuation. Consequently the next step was velocity analysis. In this case, the velocity and layer distribution it is already known. The velocity model was created in Norsar3D and imported into Promax. Based on the 3D geological model constructed in Model Builder, a P-wave velocity cube was generated and exported as a SEG-Y. The model from Norsar3D shown in Figure 15 was applied for the processing of the volumes, before and after injection. Finally NMO was undertaken using the RMS velocity resulting from the interval velocity model. The CDP stack is in Figure 16 showing an example of the inline number 34 and crossline 130; it can be notice the structure of the dipping layer and eight reflectors in the inline, and flat in the crossline direction.

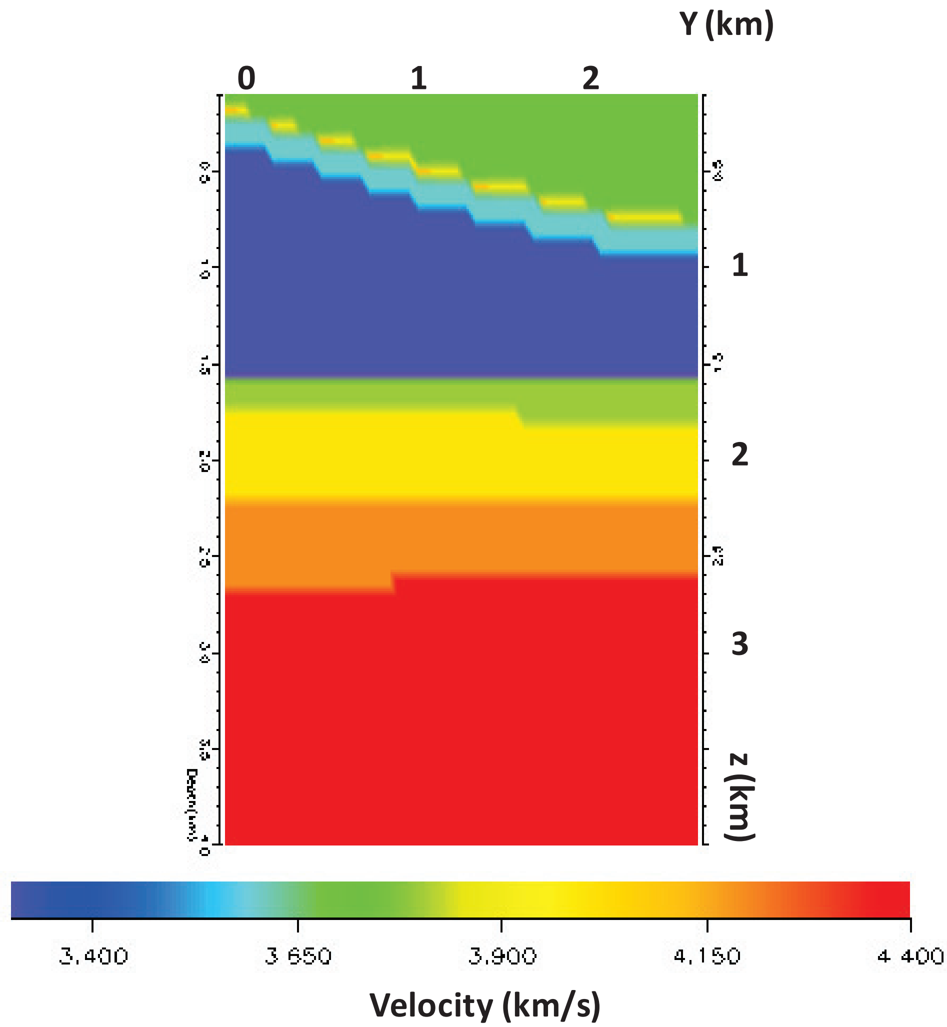



FIG. 15: P-wave velocity cube obtained from Norsar3D.

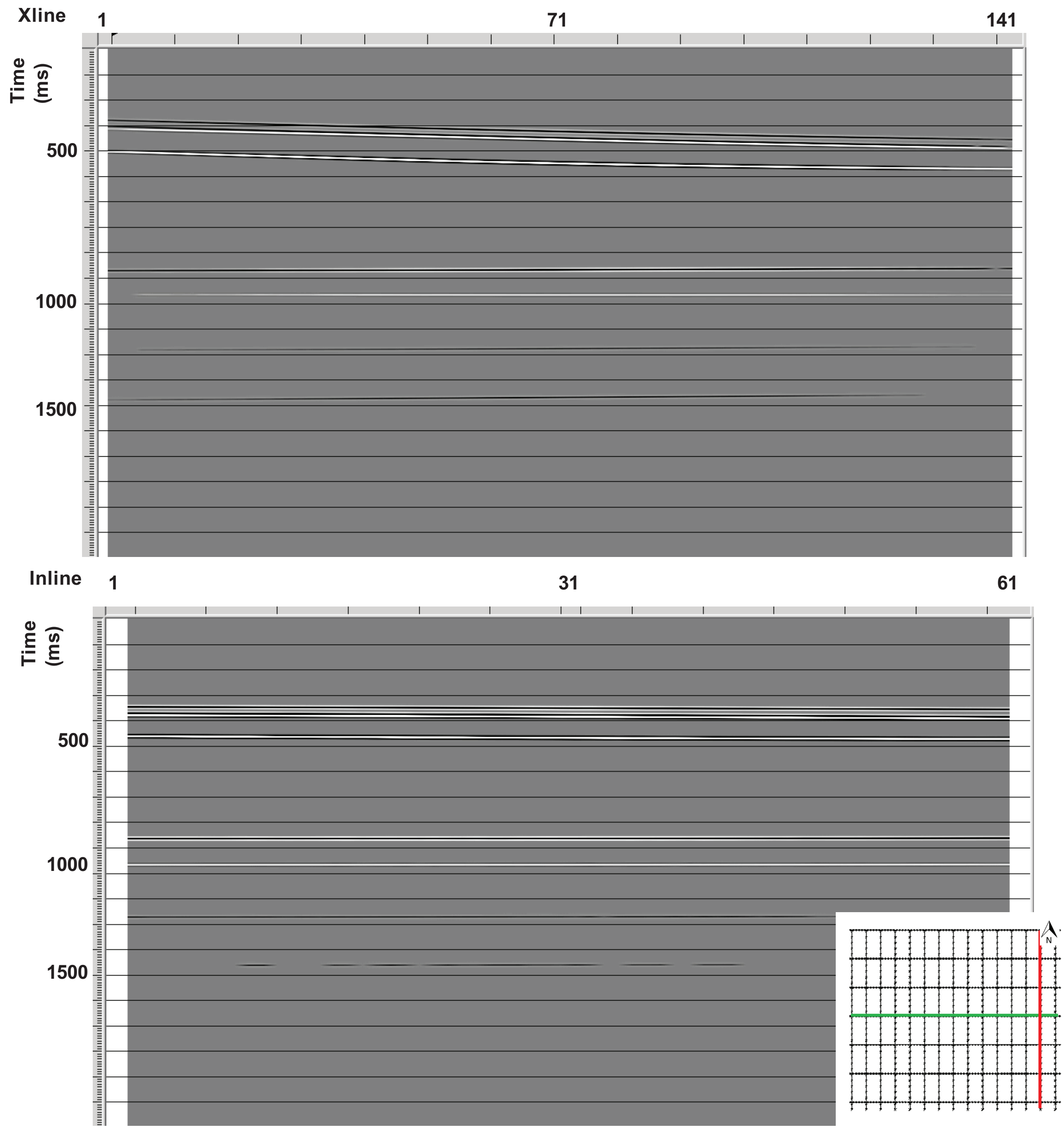



FIG. 16: CDP stack section, inline (34) and crossline (130) view.

## MONITORING RESULTS

The main objective of this study is to analyse the changes in seismic response after injecting $CO_2$ in Lower Paskapoo Fm. The goal was to recreate a more realistic scenario in terms of geology and seismic results. Two 3D seismic models were generated, one for an initial pre-injection case and the second after 3000 tonnes of $CO_2$ injection. The simplest way to establish a difference and to monitor changes in seismic is by subtracting the post-injection volume from the baseline volume. The presence of the $CO_2$ plume causes a decrease in density and P-wave velocity; therefore the expected time lapse effect would be a change in the reflectivity values across the injection area and a time delay of the reservoir basal reflectors and horizons underneath it. This velocity push down will affect LP, ED, UD,MR, BR and C. In order to visualize the changes in seismic, inline, crossline and time slice perspectives were obtained by using Hampson-Russell "View 3D" and "Strata" applications.

The first interpretation approach was to evaluate the time delay from the $CO_2$ saturated CDP stack in comparison with the baseline survey. In order to do this LP and E reflectors were picked in the zone of interest in both volumes. Figure 17 illustrates the location of the crossline, the injection area, LP and E tops. Times for LP and E are approximated 380 ms and 392 ms respectively for pre injection scenario, with a time delay after injection of only 1ms. However, even this small delay is interpretable from the seismic data.

In addition, we attempted to establish a relationship between seismic amplitude changes and the $CO_2$ saturation. In Vera and Lawton (2010), we showed the application of Shuey's approximation in order to calculate the changes in reflectivity at different $CO_2$ saturations. In this case it measured the average amplitude of the top reflectors: Seal and LP. The expected tendency was found, which a reduction in reflectivity; nevertheless the values directly obtained from the seismic section show a reduction of less than 10%, therefore the certainty of correlate this attribute directly with and specific saturation value cannot be guaranteed at this stage of the study.

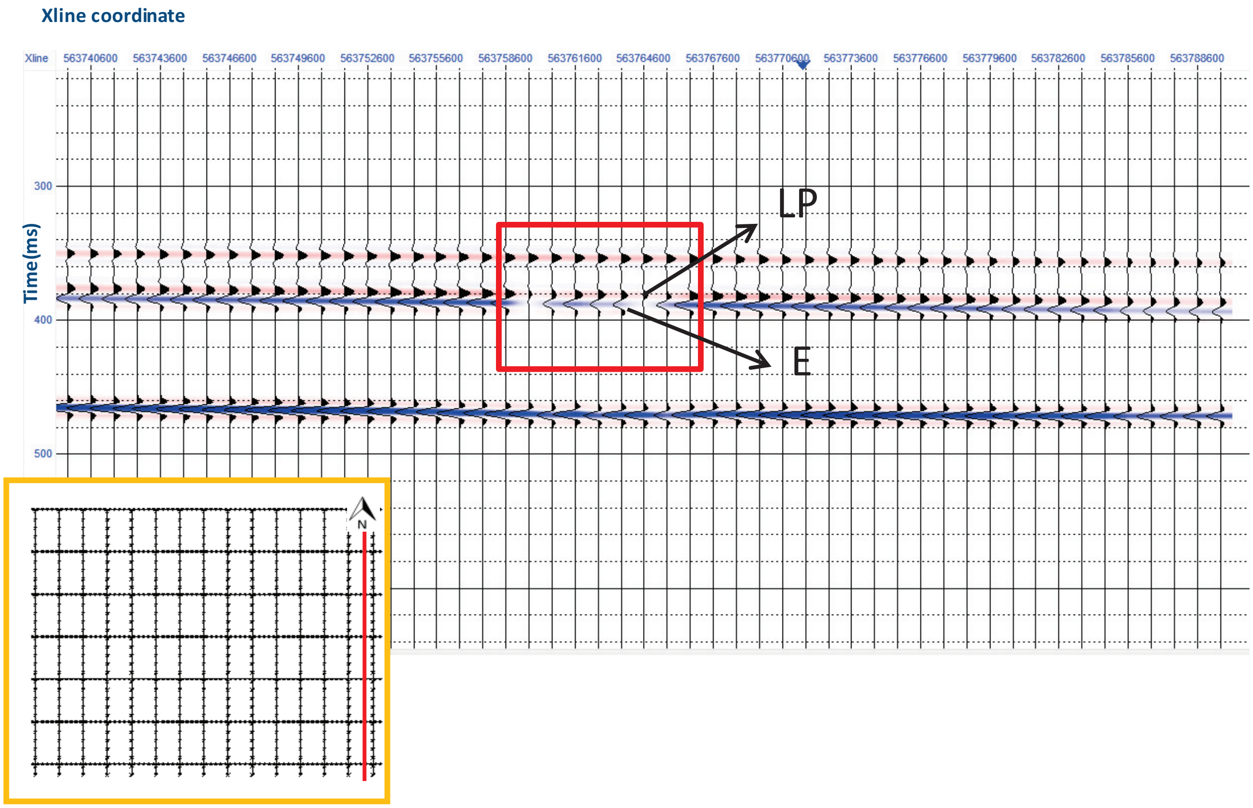



FIG. 17: Crossline 140 showing the injection area in a red square, LP and E tops.

Figure18 is the difference between the monitor and baseline volumes from an inline and crossline perspective. It is possible to appreciate a difference in amplitude and time. As well, a phase change is observed. The difference between both 3D volumes proves to be the most feasible alternative in order to appreciate the changes that seemed subtle for individual sections. In terms of size of the plume, it was found that for the first part of the plume (Seal-LP), the diameter is equal to the model. In the second part of the plume (LP-E) there is an over estimation of the size caused by the presence of gas in the overlaying section. Figure 19 shows the 3D perspective of the $CO_2$ plume and Figure 20 illustrates the changes in inline and crossline responses moving toward the North and East respectively. The anomaly affects the reflector under the injection zone as well. Finally, Figure 21 shows a time slice of the differential volume at 375ms (Seal-LP) and 385ms (LP-E), where the location and shape of the $CO_2$ plume inside the survey is evident.

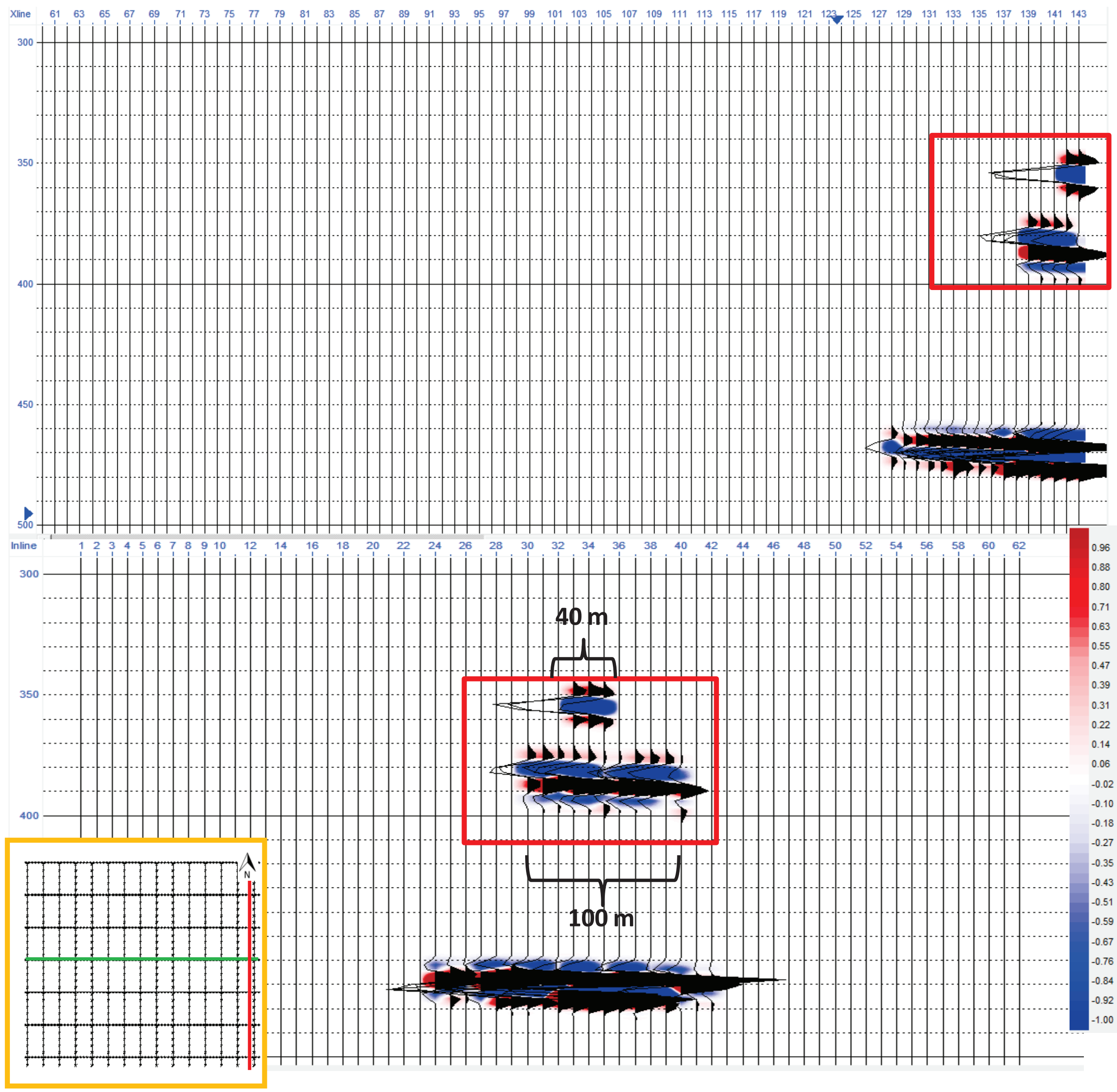



FIG. 18: Inline (top) and crossline (bottom) view of the volume resulting from the difference between the original model and the $CO_2$ saturated. The area of injection is marked in a red square.

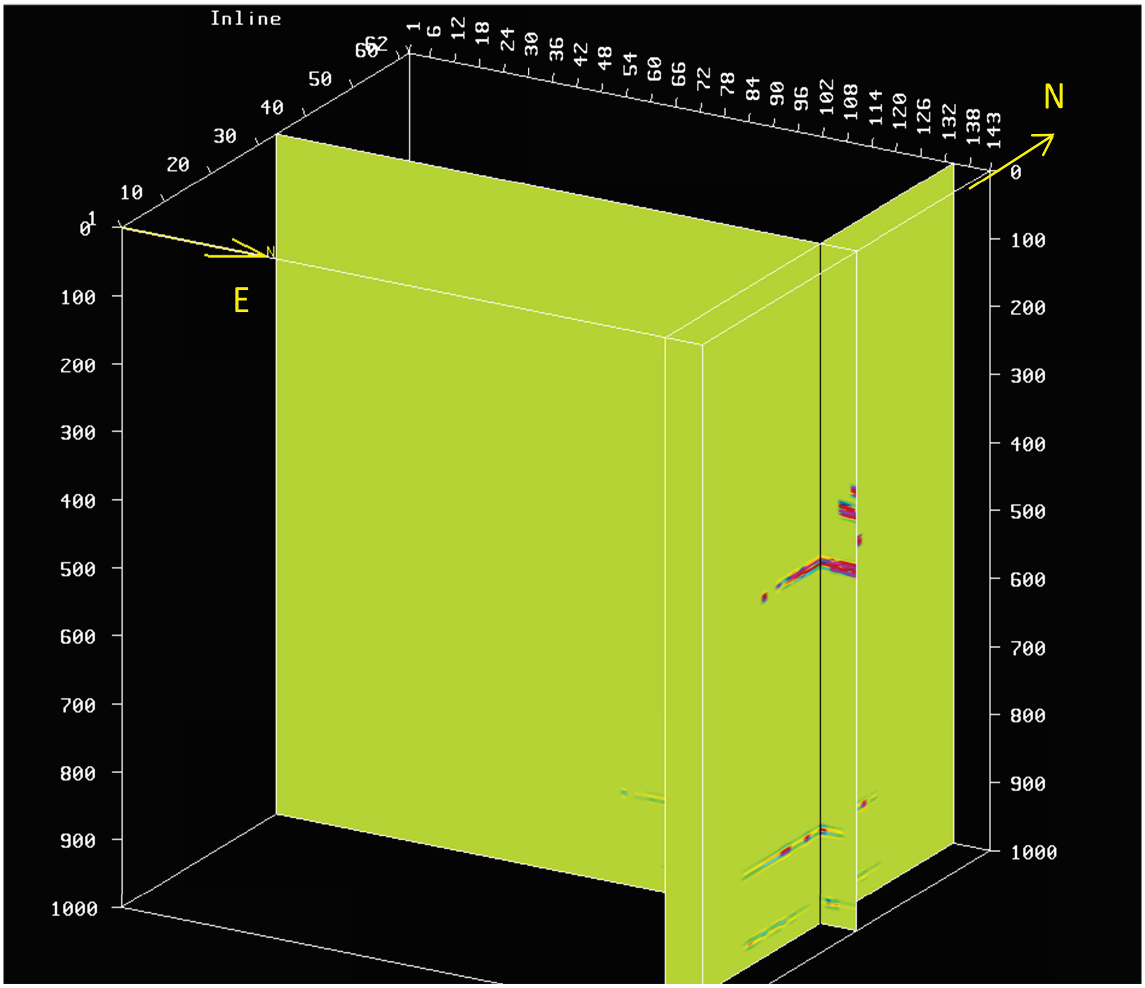
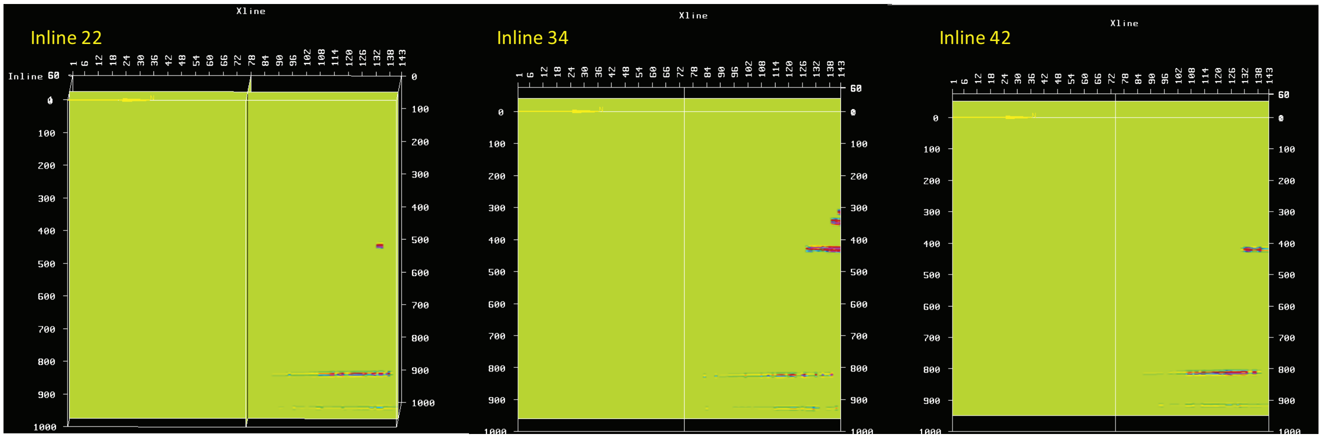
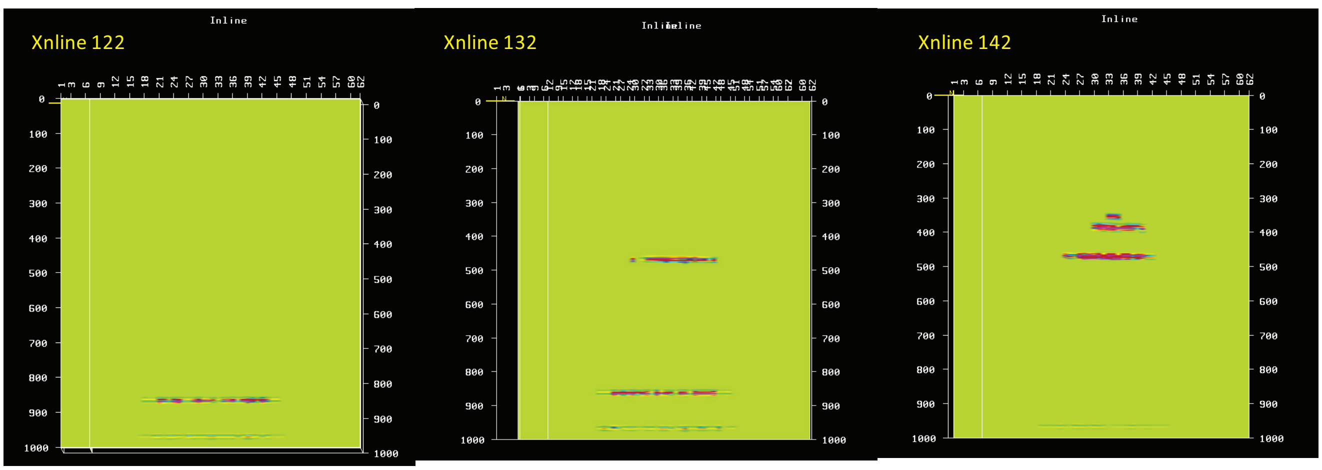



FIG. 19: 3D view of the difference volume. The anomaly is evident in the area of injection.




a)




b)

FIG. 20: (a) inline view going south to north and (b) crossline view west to east.

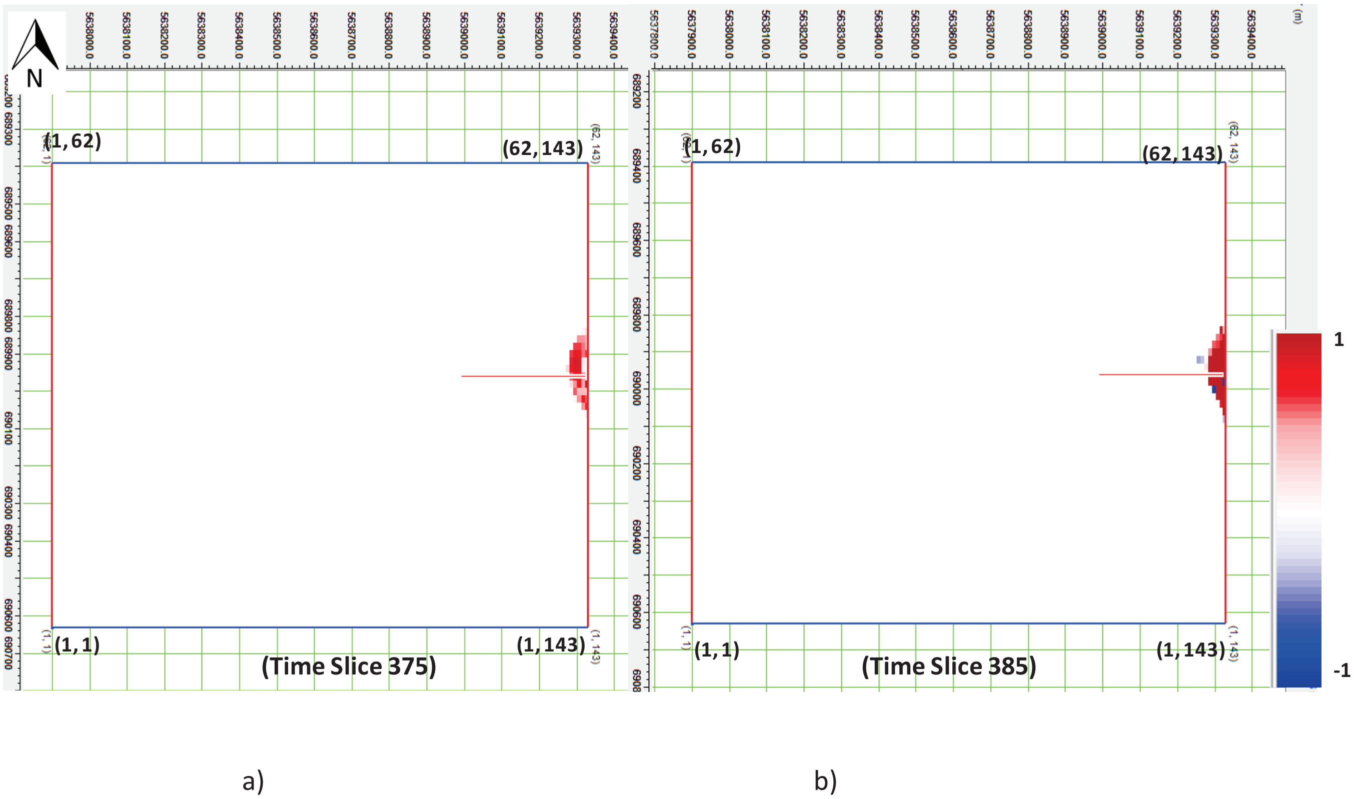



FIG. 21: Time slices (a) at 375 ms and (b) at 385 ms, showing the position on the $CO_2$ plume.

## CONCLUSIONS

- Based on seismic data and well information, it was possible to generate a 3D geological model that represents the site of injection, and a seismic model that images the Paskapoo Formation with enough precision to define the injection zone and the plume.
- The $CO_2$ plume was estimated using a static volumetric calculation considering an expansion with a cylindrical shape, with radial symmetry. This approximation of the size and shape of the plume was determined by having characteristics given by well log information, as well as porosity, thickness and final injection values such as saturation and total $CO_2$ volume.
- The properties of the plume were defined by using Gassmann substitution, depending on the lithological section and the saturation values. It was considered that a reasonable saturation value was 50%; having a transition zone with approximate 25% $CO_2$ at the advancing edge of the plume.
- The presence of the $CO_2$ plume was detected in the seismic volume by performing the difference between the initial model and the post injection model, given the changes in amplitude and time delay in the presence of $CO_2$. The presence of $CO_2$ decreases the density and P-wave velocity, diminishing the reflectivity coefficient in the top reflector of the reservoir and increasing the travel time to reach the

basal reflector. The reflectors underneath the injection zone are affected by the time shift as well.

- The reflection time delay measured for the Lower Paskapoo and Edmonton Formations is approximated 1ms. However, even this small change causes considerable changes in the seismic response, and is observable on the difference between the monitor and baseline volumes.
- The changes in amplitude, from the baseline to monitor surveys, are less than 10%. From these values it is not possible at this stage to obtain a certain correlation between amplitude and saturation.
- It is concluded that Lower Paskapoo Fm has suitable properties for a $CO_2$ storage site. The feasibility of monitoring small amounts of $CO_2$, even under small saturation changes, it has been proven by using fluid substitution and seismic modelling,

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