

## Development of a geostatic model for a geoscience field research site in Alberta

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### Summary

A 5 km x 5 km geostatic property model of effective porosity and permeability was constructed for a shallow primary and deeper secondary injection interval at approximately 290 m and 480 m depths, respectively. The model is populated with effective porosity and permeability using existing wireline data from 75 wells with a Gaussian Random Function Simulation algorithm. The effective porosities of the primary and secondary injection intervals range from 0-27% and 0-18%, respectively. The primary seal interval consists of silty-sands, shales, and impermeable coal layers. The secondary seal interval consists of calcareous mudstones with bentonite layers and high illite content. The 5 km x 5 km property model was updated using two 3-D seismic reflection volumes and existing sonic log data. A time-depth relationship was configured by completing 8 well-ties. Velocity modeling was completed for depth domain conversion. Both injection intervals appear to be promising injection sites for CO<sub>2</sub> and have since been assessed for risk. The 1 km x 1 km GFRS area will be tested further using Eclipse in Petrel™ 2014.1 for computerized fluid injection simulation to study the behaviour of the CO<sub>2</sub> in the subsurface.

### Introduction

In taking action to mitigate greenhouse gases emitted into the atmosphere primarily from fossil fuel sources, carbon capture and storage is a method of sequestration to reduce CO<sub>2</sub> emissions. The GFRS will serve as a research development site of advanced technologies for monitoring subsurface fluid flow. The study area is within the province of Alberta, located 188.9 km southeast of Calgary (Figure 1) in Section 22, Township 17, and Range 16 west of the 4<sup>th</sup> Meridian.

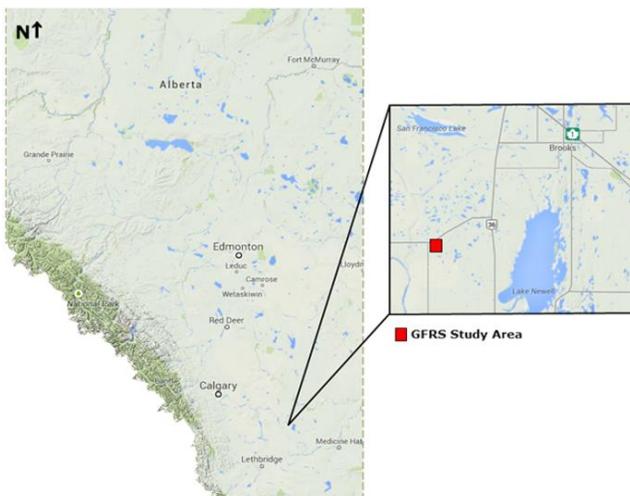


FIG. 1. Location of the GFRS study area in Alberta (© Google, INEGI 2014).

The Basal Belly River Sandstone is the shallow target, characterized as a regressional shoreline sandstone (Hamblin and Abrahamson, 1996) and is recognized as the basal unit of the Foremost Formation, deposited during the Late Cretaceous within the Western Canada Sedimentary Basin (WCSB) in the Montana Group at approximately 290-310 m depth. The reservoir is described as fine- to medium-grained sandstone that has poorly to well sorted, angular to sub-angular grains packed loosely with calcite cement (Hamblin and Abrahamson, 1996). The sandstone was interpreted to reach a maximum thickness of 12.5 m in the GFRS study area.

The Medicine Hat Member is the second deeper target of interest, located at approximately 480 m depth and occurs below the First White Specks Member in the Colorado Group. The formation consists of at least three upward-coarsening very fine-grained sandstone and siltstone units that were deposited in a shallow marine shelf environment during the Santonian stage (Leckie et al., 2013). These units are a heterogeneous mix of thinly bedded, very-fine to fine-grained sandstone and coarse siltstone beds (Schroder-Adams et al., 1997). The units are described to be compositionally mature litharenites that are graded, calcareous, and are mottled as a result of the bioturbation (Schroder-Adams et al., 1997).

The objective of this project is to develop a geostatic model that incorporates geological and geophysical information of the GFRS area to provide a prediction as to how fluid simulation will behave in both the shallow primary and deeper secondary injection intervals. The GFRS will serve as a pilot site for researchers of all suits, and act to test cutting-edge measurement monitoring and verification (MMV) technologies for the injection and storage of 1000 tons of CO<sub>2</sub> injected per year. The site will also aid in the development of new MMV technologies, as well, to improve and enhance 4-D seismology for fluid containment and conformance.

The project has 198 wells with digital LAS files imported that include wells outside of Township 17, within a 10 km radius from the main onsite well 7-22. The wireline data suite is comprised of gamma ray, spontaneous potential, compressional sonic, shallow-deep resistivity, bulk density, and lastly density and neutron porosity logs. Few core data measurements were also used to develop relationships for the porosity and permeability calculations. Effort was focused on a total of 75 wells for formation well top interpretation, and only 17 of those wells are within a 5 km radius of the main well 7-22.

## **5 km x 5 km Property Model**

The property model incorporated simple vertical pillar gridding, with an orientation N-S inline with the groundwater flow in the shallow primary target. The defined volume is 200 x 200 x 922 (nI x nJ x nGrid Layers) giving a total of 36 million 3-D cells. The GFRS is located in the Prairies, with simplistic layer-cake geology and no faults intercepting the model. The horizons honour the surfaces, where surfaces were generated through interpolation honouring the interpreted well top data. The layering of the cells references the surfaces, and zone division of each layer was based on cell thickness. Zones of seal and target intervals were given a cell thickness of 0.5 m, and a cell thickness of 5 m to zones of non-important intervals.

Two main properties were used to populate the geostatic model – effective porosity and permeability. Property calculations included the neutron and density porosity cross-plot method to calculate the total porosity (Figure 2). A volume of shale calculation using the gamma ray log was then completed on the entire log suite, using a maximum of 95 API and a minimum of 50 API to define the shale, silty-sands, and sands, respectively. Utilizing the total porosity and volume of shale resultant logs, the effective porosity was then computed. Limited core data was available that extended in the greater 10 km radius from the main well 7-22, where a porosity and permeability relationship was established.

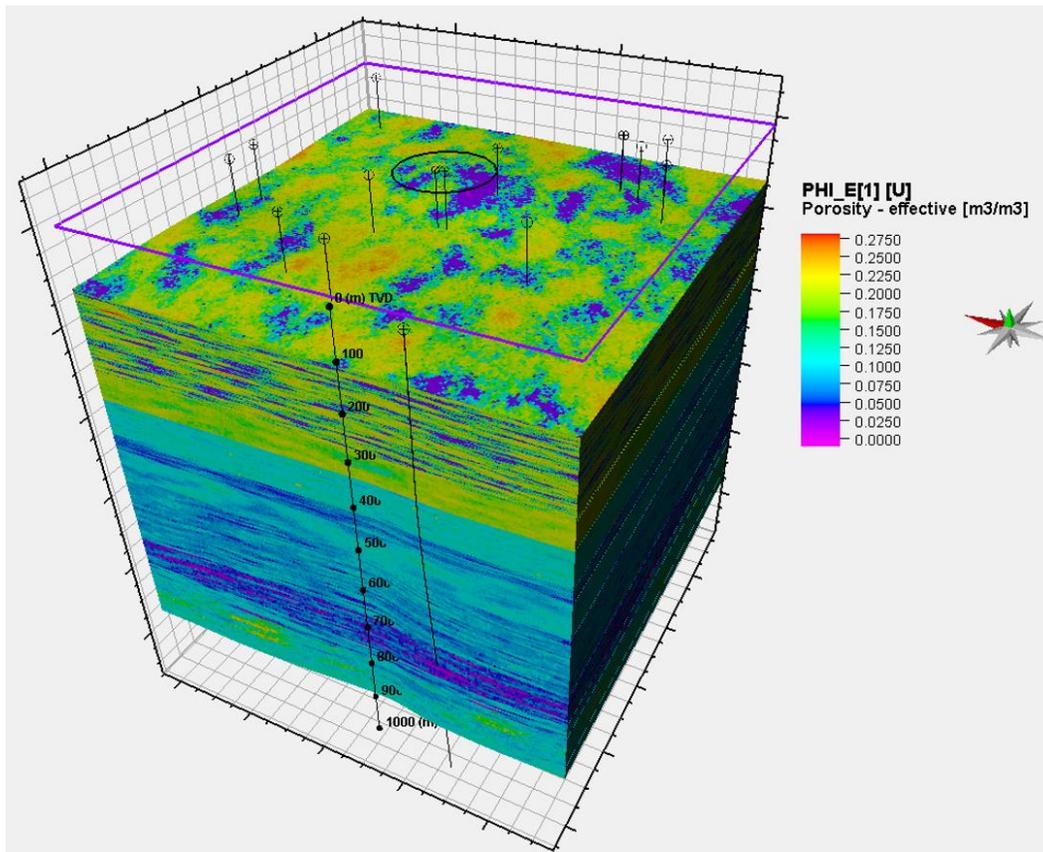


FIG. 2. The 5 x 5 km property model of the GFRS with each zone populated with effective porosity. The highest effective porosity modeled is 27.5% (red) and the lowest is 0% (pink).

Upscaling the computed properties into the model cells was completed using a Gaussian Random Function simulation algorithm. The parallelized algorithm is a conditional simulation, which utilizes both kriging and unconditional simulation and is able to model the expected variability and distribution in the input data. Table 1 shows the difference in value ranges for effective porosity and permeability for computation runs completed in May and November 2014.

Table 1. Range of effective porosity and permeability values for the primary and secondary target and seal intervals computed in May and November 2014.

Interval	Type	$\Phi_E(\%)$		$\kappa$ (mD)	
		May 2014 Computation	Nov 2014 Computation	May 2014 Computation	Nov 2014 Computation
Foremost Fm	Seal	0-26	0-28	<b>0-55</b>	<b>0-360</b>
BBRS	Target	0-25	0-27	<b>0-85</b>	<b>0-300</b>
Colorado	Seal	0-17	0-14	0-0.46	0-0.57
Medicine Hat Mbr	Target	0-13	0-18	0.02-2.5	0-1

From the table, minor changes in value ranges for the effective porosity for both May and November 2014 computations. The greater differences are outlined in red, where the permeability values have increased. With consideration of the effective porosity and permeability relationship, the higher bracket permeability values of 300 mD and 360 mD are most likely to resemble the air permeability of which has yet to be corrected for overburden pressure, and fluid being injected or produced at the formation.

Whereas the lower bracket permeability values of 55 mD and 85 mD are likely to be what the fluid of injection will see at the formation after corrections have been applied. (Pedersen, 2014)

To gain a better understanding of the uncertainty within the data, a P10/50/90 framework was used to characterize the conservative, typical, and optimistic ranges within the distribution of the effective porosity data in each target and seal interval. With these three values for each interval, using the effective porosity – permeability relationship, the P10/50/90 permeability values were computed.

#### 4 km x 5 km Geophysical Model

Two 3-D seismic reflection volumes were available for interpretation, including the 1997 vintage 3D/1C dataset courtesy of Cenovus Energy, and the May 2014 3D/3C dataset courtesy of CMC. Within the extent of the seismic volumes, eight well-ties and synthetic seismograms were completed (Figure 3). A replacement velocity of 2600 m/s was used, and hung at a seismic reflection datum of 800 m. No checkshot data was available, thus the time-depth relationship (TDR) was developed on the sonic logs available. A zero-phase Ormsby Wavelet (15/20-75/95), with length of 200 ms and a sample rate of 2 ms was used for creating the synthetic seismograms. Minor stretch and squeezing was done to match the subsurface reflectors in the seismogram to the seismic volumes.

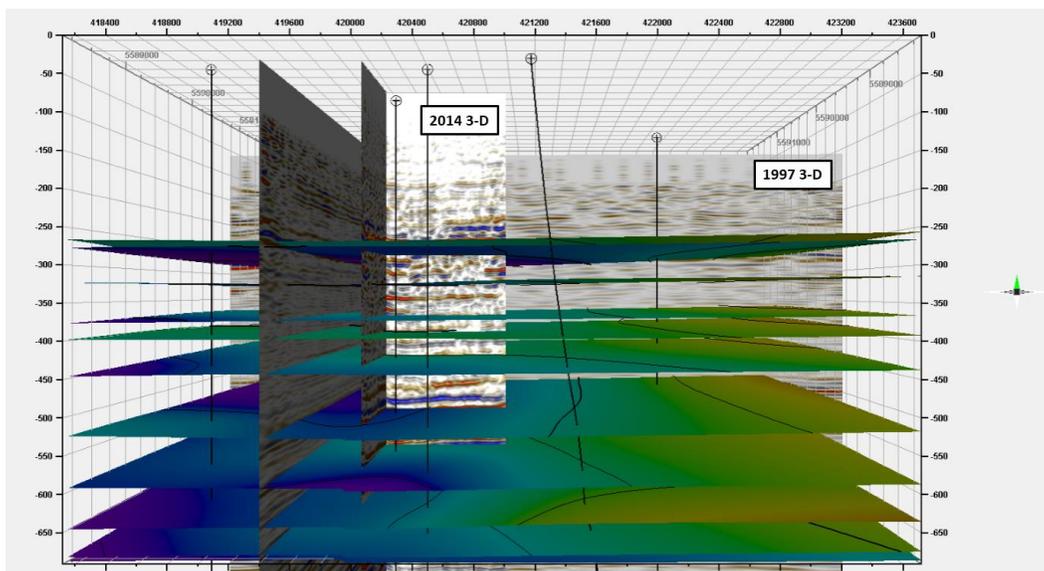


FIG. 3. A display of the two 3-D seismic reflection volumes, 8 wells with completed well-ties, and time surfaces intersecting these as a result of seismic horizon interpretation.

Velocity modeling was completed to finalize the depth conversion of the geophysical model, utilizing the TDR developed by the well-tie process and velocity constants through the blocked sonic logs. The 5 km x 5 km property model was updated by the 4 km x 5 km geophysical model through the weighted input of horizons. The updated 5 km x 5 km integrated geostatic model has surfaces weighted 75% depth-converted seismic horizons and 25% well-top interpretation input. For future work, the geostatic model will be clipped to the GFRS 1 km x 1 km area for subsurface fluid simulations and analysis.

#### Conclusions

A 5 km x 5 km geostatic model was developed about the main well 7-22 in the GFRS area in Newell County, Alberta. Existing wireline and 3-D seismic reflection data was used to interpret the subsurface horizons to a depth of 700 m (top of the Mannville Group).

The two main geological properties that were focused on to populate the 3-D model that were chosen include effective porosity and permeability. Using the limited core data analyses, a relationship between porosity and permeability was established for the target and seal intervals. The properties were populated into the model by utilizing a Gaussian Random Function Simulation algorithm. To gain a better understanding of the uncertainty within the data, a P10/50/90 framework was used to characterize the conservative, typical, and optimistic ranges within the distribution of the effective porosity data in each target and seal interval.

A velocity model was constructed utilizing the time surfaces which included interpretation from both the TDR from the synthetic seismograms and well-ties, as well as the subsurface reflector interpretation on both the 1997 and 2014 3-D seismic volumes in the GFRS study area. Depth conversion involved using the produced velocity model, TDR, and velocity property modeling for each subsurface formation. The depth-converted geophysical model was integrated into the 25 km<sup>2</sup> property model to update the subsurface formation locations using a weighting factor of the different data sets.

A 1 km x 1 km clipped region of the 25 km<sup>2</sup> integrated geostatic model about the main 7-22 well for the two injection and corresponding seal intervals, which will be used for the CO<sub>2</sub> fluid simulation. From the P10/50/90 framework, the attributed pore volume realization assigned to each percentile will be further used in the simulation for the CO<sub>2</sub> injection.

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