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A framework for full waveform modeling and imaging for CO_2 injection at the FRS project

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Summary

The Field Research Station (FRS) is a project developed by CMC Research Institutes, Inc. (CMC) and the University of Calgary. During the injection CO2 in the target layer (300 m depth), dynamic parameters of the reservoir as pressure and phases saturation will change and they can be derived of fluid simulation result. For the project, strategy is five years' injection with constant mass of CO2 equal to 1000 t/yr.

Time-lapse seismic analysis of reservoir was assessed by seismic finite difference time domain (FDTD) modeling based on an acoustic velocity-stress staggered leapfrog scheme. The FDTD is 2nd order in time and 4th order in space on Central Finite Difference (CFD). The boundary conditions are set on all edges except surface, based on a perfectly matched layers (PML) approach. The effect of CO2 substitution is a time delay in time domain seismic data under the reservoir because of velocity reduction and also a change in amplitude of reservoir reflections. Based on synthetic models, the difference between base model and time-lapse model after 5 years of CO2 injection reveals a significant seismic result, because it is a near-surface reservoir. Given that the seismic resolution is high because of the shallow target depth and acquisition parameters, it is expected to improve that seismic monitoring will be an effective method to monitor the CO2 injection.

Introduction

The project area covers 1*1 km and it is at a direct distance of 20 km from Brooks city and 10 Km of Lake Newell (the red squares shows the project area, FIG.1). The research plan is injection a very controlled and limited amount of CO2 in the shallow layers to monitor migration and behavior of gas plume by seismic and other methods.

This paper covers four parts of research. they are:

Making a Geomodel

Fluid simulation

Rock physics study

Seismic synthetic modeling

The next year, field study will continue by CO2 injection and seismic time lapse acquisition. Now all models are synthetic that will be compared with real data and it can show off a new method for higher accuracy and less error in seismic time lapse monitoring.

Our research method was defined in FIG.2. It demonstrates research elements and relation between them for optimizing data in a reservoir.

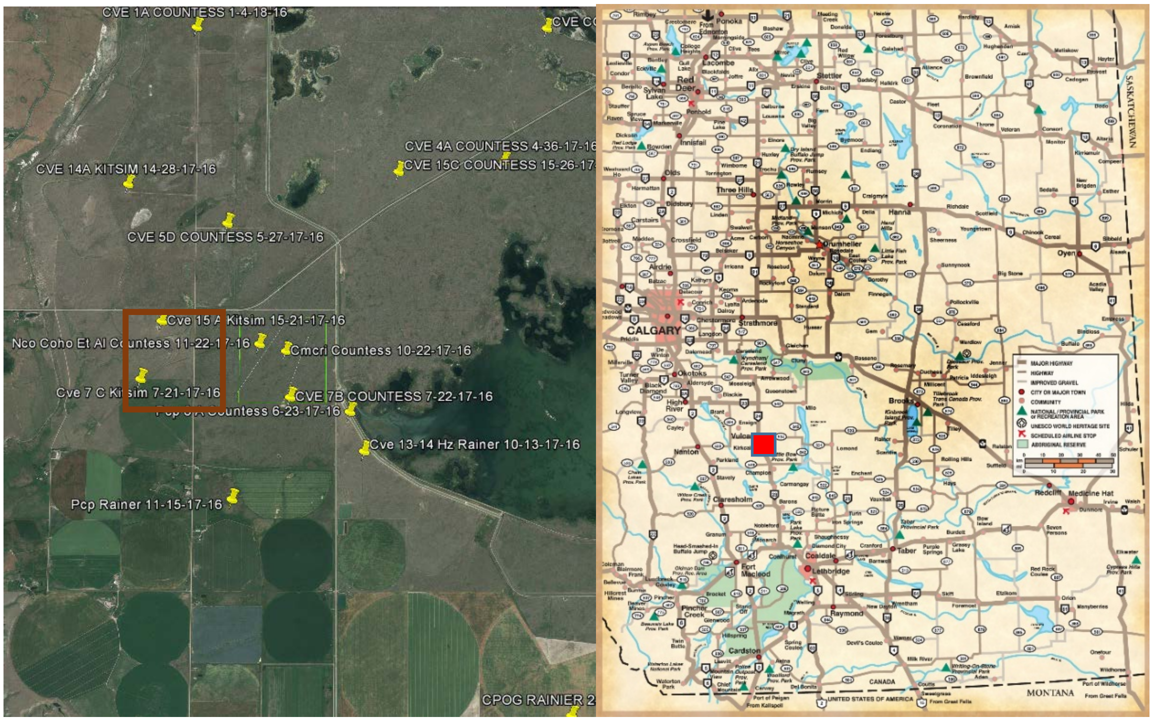

FIG.1. Location of the project (satellite image from Google Earth)

GEOMODEL

For the mass transfer's calculation and fluid simulation, it needs to collect data from different disciplines, that included:

Geological set and studies

Seismic data and result of interpretation and UGC maps in depth domain

Well log data and petrophysical interpretation

Core analysis

Facies analysis

Procedure for analysis data are:

Permeability and porosity estimation

Make a suitable grid

Upscaling well logs

Variogram analysis

Final estimation by Kriging

Model validation

For the permeability modeling, Timur-Coates (KTIM) and the Sclumberger-Doll-Research (KSDR) models from NMR log were available and KTIM was used for Kx,y modeling. Because of layering and sharp change in the vertical permeability (or perpendicular to the geological layers), Kz was considered equal to 10% of KTIM. Also an average of porosity logs was considered for geostatistical porosity model. result of geostatistical analysis on data can make a geomodel that is a base for fluid simulation. An accurate geomodel can guarantee a precise result for fluid simulation.

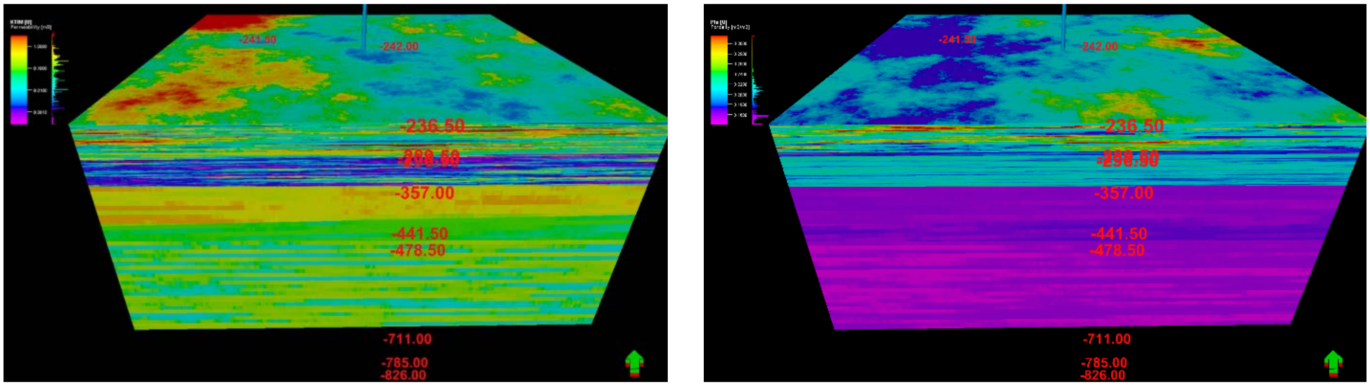

Fig.2. Porosity (up) and Permeability (X, Y) (down) models, size of geomodel is 1*1 km.

The pressure and saturation

The CO_2 saturation amount is related to trapping efficiency (Bachu, 2013) and irreducible water amount. For the low permeability area as the injection target in sandstone, trapping efficacy can be up to 65 percent (Bachu, 2013). The irreducible water amount can be calculated by using difference of total saturation (by Archi's equation) and free fluid from NMR log.

However, simulation for selected injection strategy shows that maximum saturation in the injection point can reach to maximum 70% and the reservoir pressure is going higher than fracking pressure equal to 140 bar. The numerical simulation result is going directly to the next part for the rock physics study and velocity/density/acoustic impedance calculation.

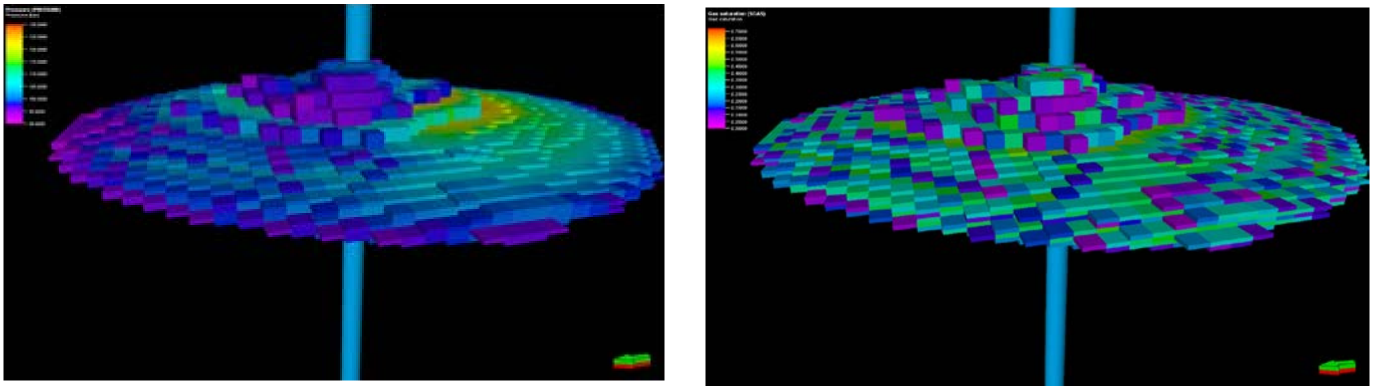

FIG .3. The final result of the fluid simulation , right CO2 gas saturation distribution and left pressure after five years CO2 injection.

FWI MODEL

As mentioned in the previous parts, velocity and density have changed after CO2 injection and it can has effected seismic data. In This part two models were made for the base data before and after injection. In order to perform the FWI of CO2 injection, an acoustic approximation is used for time laps waveform analysis and solved according to Seismic Finite Difference Time Domain (FDTD) modeling code based on acoustic velocity-stress staggered leapfrog scheme.The FDTD is 2nd order in time and 4th order in space on central finite difference (CFD). The boundary conditions are set on all edges except surface based on Prefectly Matched Layers (PML) of the following references. The first test is for a single shot data with 500 m geophones spread in each side of well. Position of the shot is located on the well. Figure

4 shows a cake layers' model of p wave velocity according to CMC well data, and figure 6 are synthetic data for pressure, vertical and horizontal displacements for the base model.

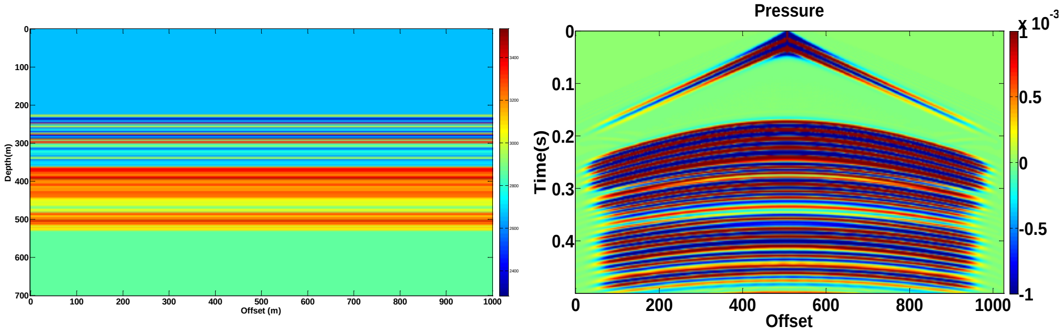

FIG.4. Initial velocity model for the project area made by CMC main well data (left) and synthetic shot (pressure) for initial model (before injection), (GI=3 m)

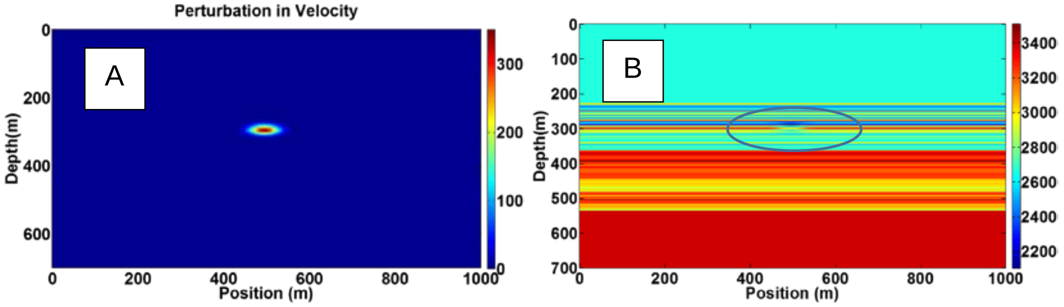

FIG.5. A and B. Velocity perturbation due to gas injection calculated by Gassmann's equation in Belly River sandstone

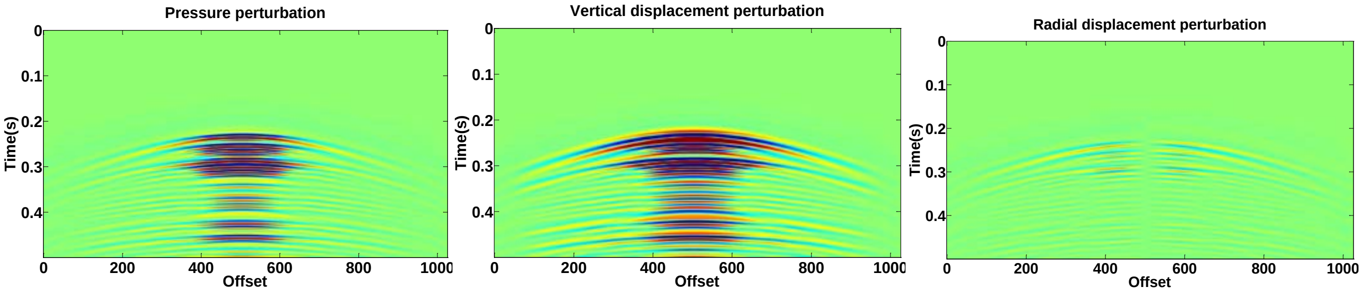

FIG.6. Pressure, vertical and radial displacements differences in raw shot model (time lapse-base), model was built by 1 km geophones spread with RI=3m.

For a complimentary seismic time-lapse research, we focused on a full 2D seismic model with a full data processing with RTM (Reverse Time Migration). RTM algorithm assumes two-way wave equation but associated imaging condition is one-way wave equation (i.e., convolution of downgoing and upgoing waves). Result of difference between the time lapse and base generating synthetic models after processing has been demonstrated in (FIG.7.). In this model, receivers spread is 1 km long with 200 shots and GI=SI=3m.

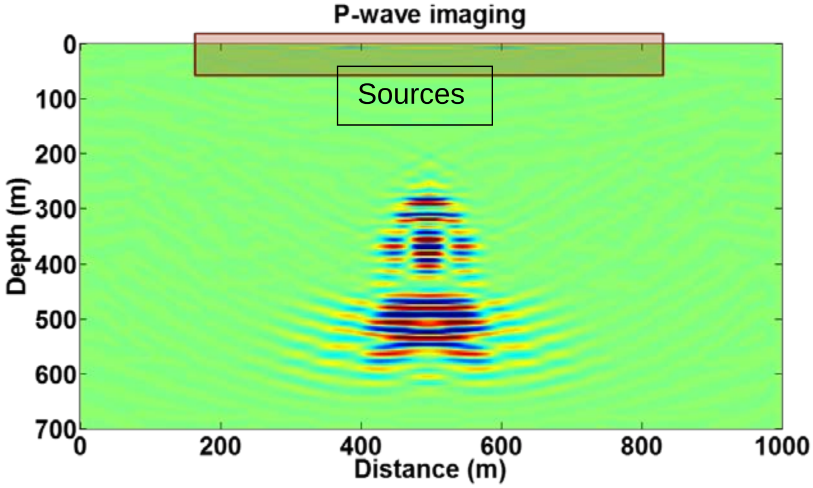

FIG.7. Migrated difference of a 2D line acquisition on the reservoir, the image is differentiated in second order to remove the low frequency artefact of Reverse Time Migration.

Conclusion

For this project we made at least five different geomodels with the different data sets and sizes, Main geomodel made by CMC injection well data and (1*1 km) it tested for the simulation. The fluid simulation result demonstrated a CO2 plume as ellipsoid with 120 m radius and 12 m thickness. For the simulation two strategy were used that result of constant mass injection was target of rock physics study and seismic modeling. The saturation of CO2 reached to maximum 70 percent and, the bulk modulus and p-wave velocity were estimated by Gassmann's equation and also Acoustic Impedance demonstrates an decrease up to 7% in the core of the reservoir.

In the seismic modeling part, a single shot on the well with 1 km receivers spread and GI=3 m and a 2D line were modeled. In the row shot it is possible to recognize a remarkable change for the time lapse model. A difference of 2D model (base model-time lapse model) was migrated and it reveled a realistic seismic change. Area has very simple geological set, dip angle of layers is less than two degrees, Surface is flat with no static problem and injection zone is in very shallow depth. So the next step will be a field injection and time lapse seismic acquisition, that it can be compared with the synthetic model. We expect that inversion and study of real seismic time lapse data also can improve the geomodel and simulation result and one step forward in the seismic 4D reservoir studies.

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