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

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ABSTRACT

The Field Research Station (FRS) is a project developed by CMC Research Institutes, Inc. (CMC) and the University of Calgary. During the injection CO_2 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 CO_2 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 CO_2 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 CO_2 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 CO_2 injection.

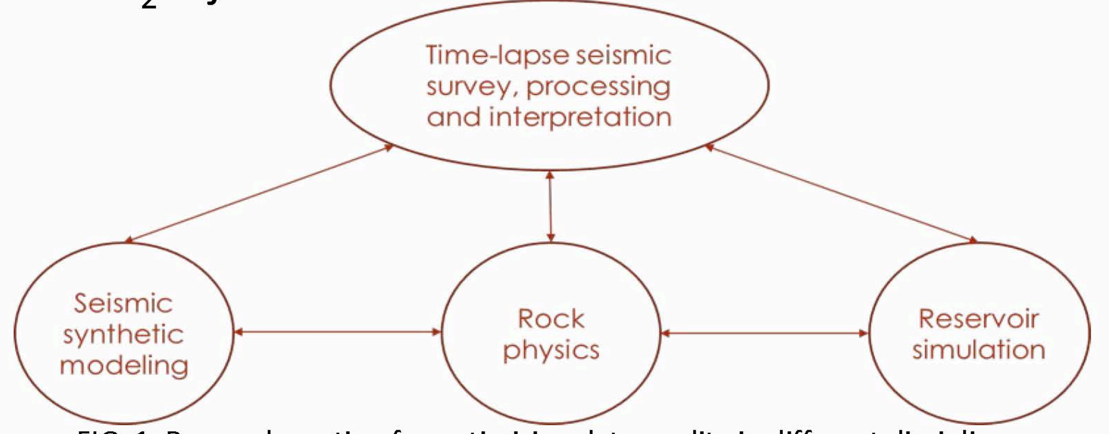

FIG. 1. Research routine for optimizing data quality in different disciplines.

GEOMODEL

For the mass transfer's calculation and fluid simulation, it needs to collect data from different disciplines(FIG.2.).Procedure for analysis data are:

1-Permeability and porosity estimation

2-Make a suitable grid , 3-Upscaling well logs

4-Variogram analysis

5-Final estimation by Kriging

6-Model validation

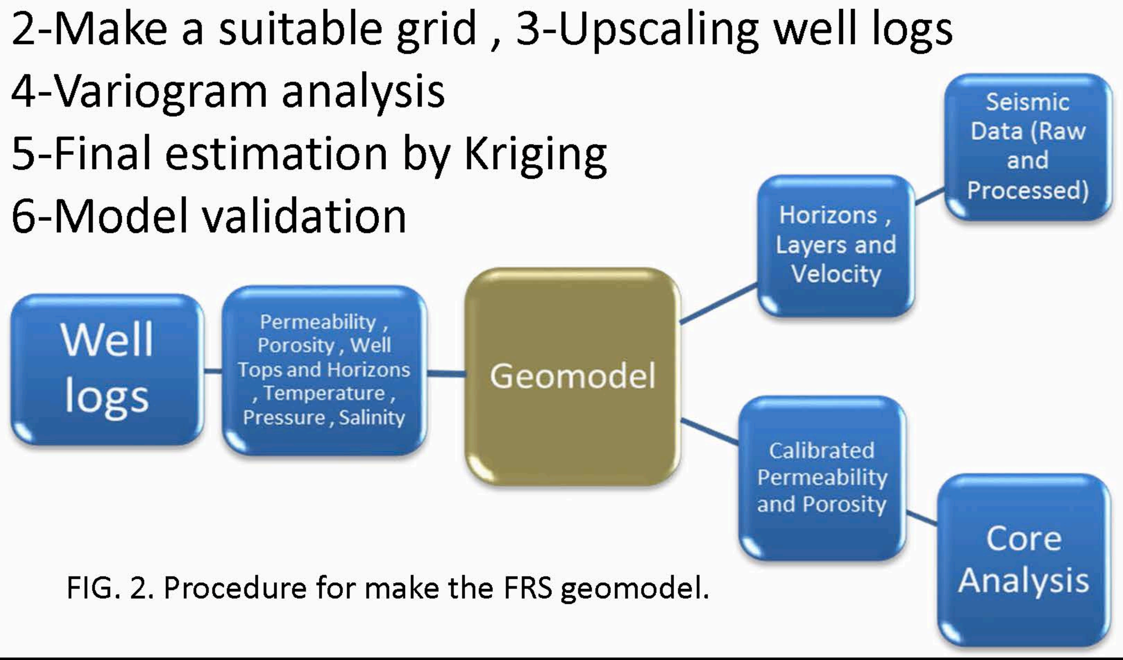

FIG. 2. Procedure for make the FRS geomodel.

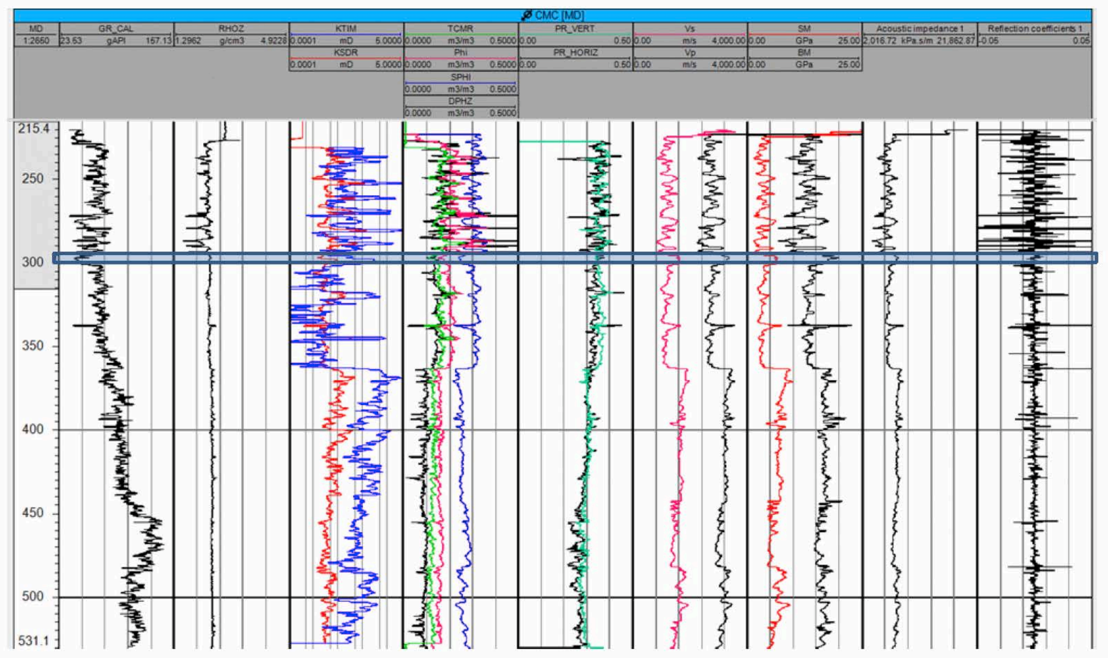

FIG.3. CMC Well log data is the main base for geomodel .The injection zone (Belly river sandstone) is shown by a blue rectangle.

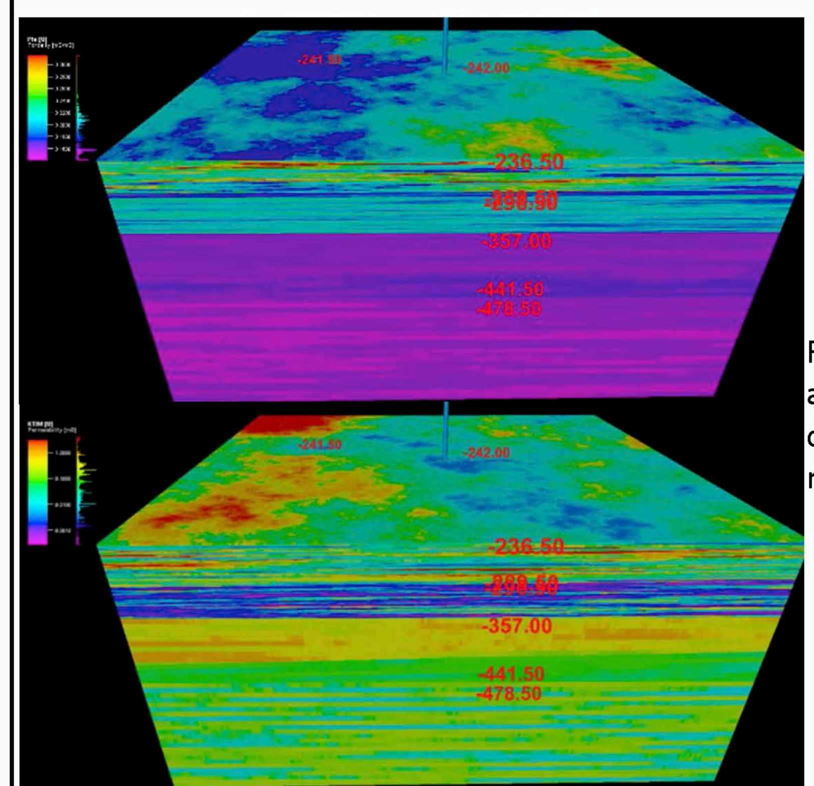

FIG. 4. Porosity (up) and Permeability (X, Y directions) (down) models, size is 1*1 km.

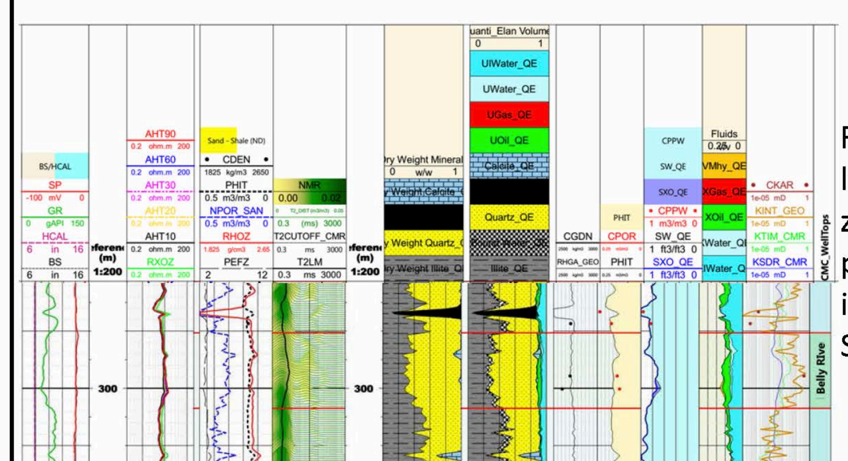

FIG. 5. Log data and lithology of injection zone (Belly river) by petrophysical interpretation, Schlumberger.

FLUID SIMULATION

Primary data for simulation

For the simulation, some data as PVT table, injection strategy, relative permeability, water salinity and rock compressibility constitute the essential data. For the relative permeability, a study about CO_2 in sandstone formations in Western Canada was available and used for the calculation (Bachu,2013). Water salinity also assumed a very light amount as 1000 ppm.

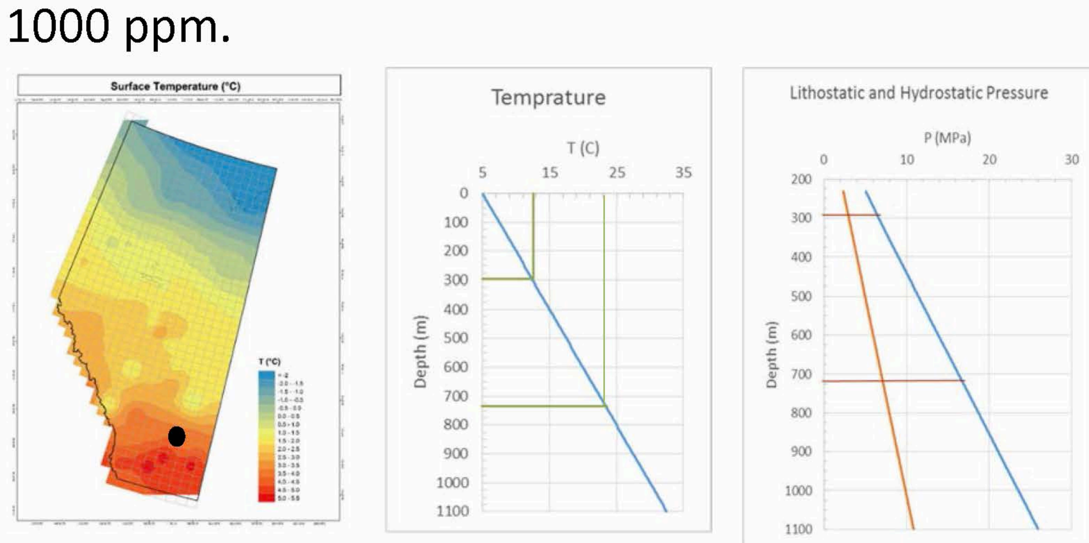

FIG.4. Surface temperature in Alberta (dark circle is on the project area) and underground temperature according to temperature increase rate as 23.5 °C per Km, third shape is lithostatic pressure according to well log data and hydrostatic pressure.

The injection strategy is considered as a constant mass amount of CO_2 equal to 1000 ton/years for five years.

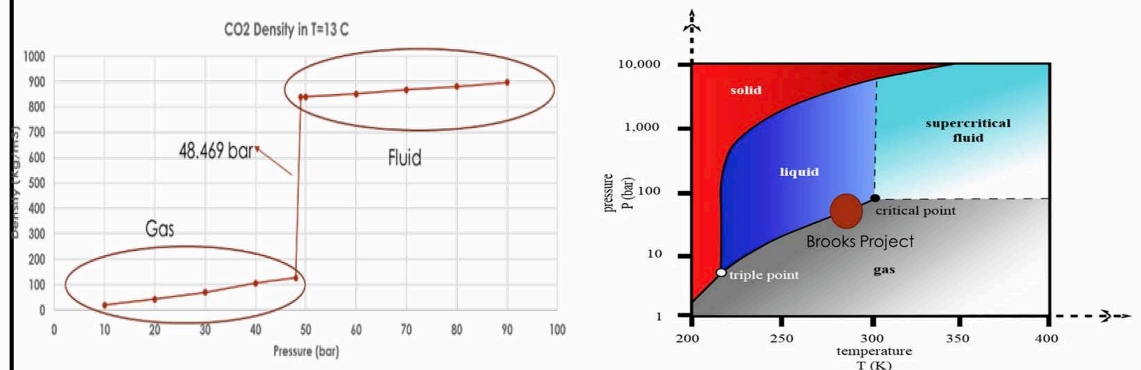

FIG. 5.Left:CO2 Phase change during the injection because of pressure change. Right:CO2 phase diagram (red circle shows the FRS reservoir condition).

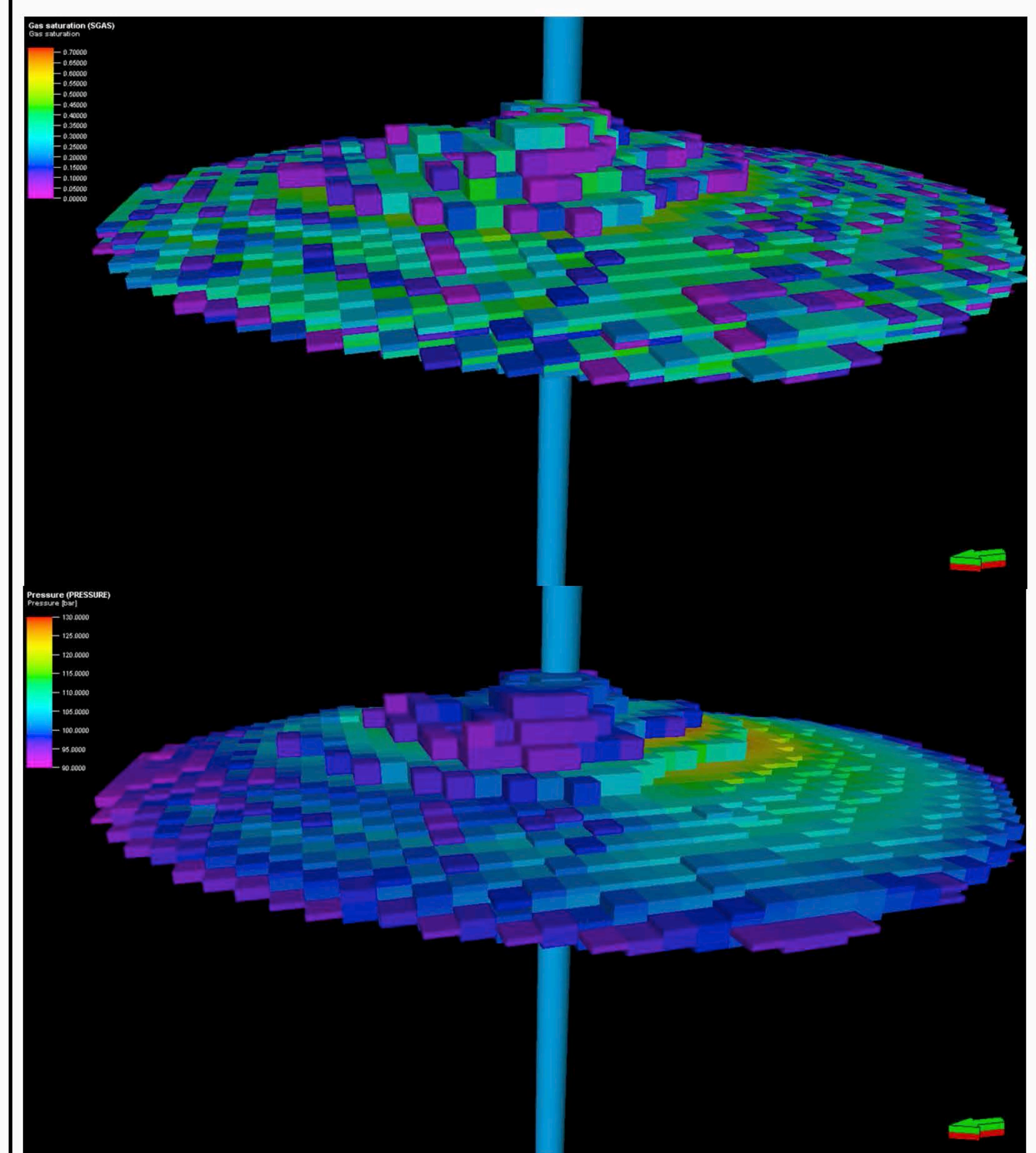

FIG 6. The final result of the fluid simulation , Top CO2 gas saturation distribution and bottom the reservoir pressure after five years CO2 injection.

FWI SEISMIC MODEL AND IMAGING

In this part, two models were made for the base data before and after injection. In order to perform the FWI of CO_2 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).

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 15 shows a layer cake model of P-wave velocity according to CMC well data, and Figures 8,9 and 10 are synthetic data for pressure, vertical and horizontal displacements for the base model.

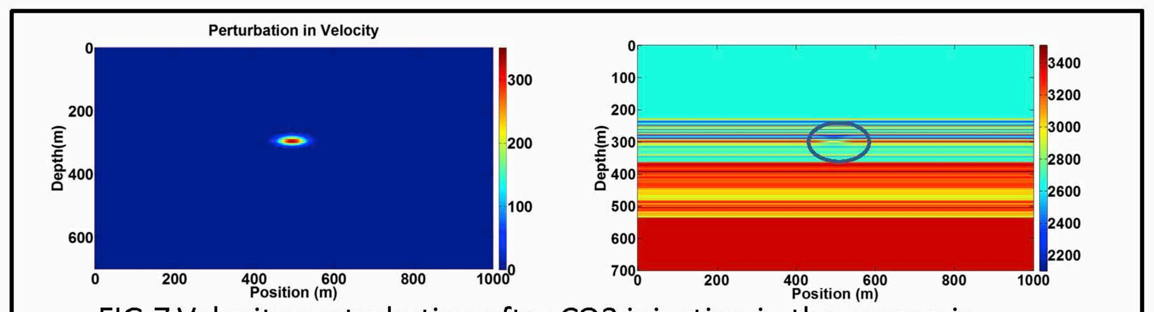

FIG.7.Velocity perturbation after CO2 injection in the reservoir.

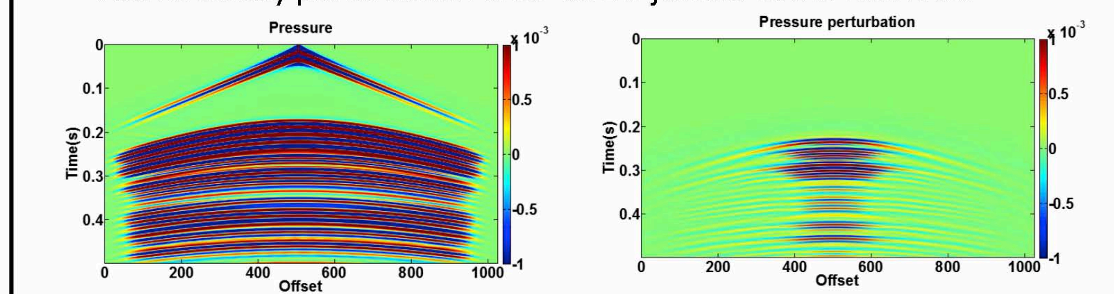

FIG.8.Left a single shot before injection (base seismic) and pressure perturbation (monitor seismic – base) after injection.

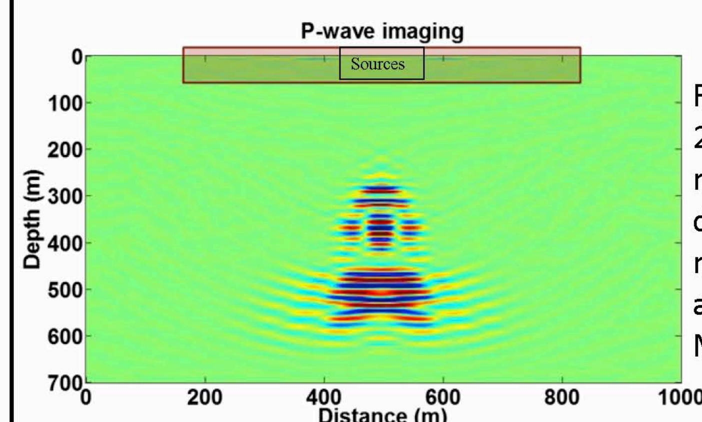

FIG.9.Migrated difference of a 2D line acquisition on the reservoir, the image is differentiated in 2nd order to remove the low frequency artefact of Reverse Time Migration.

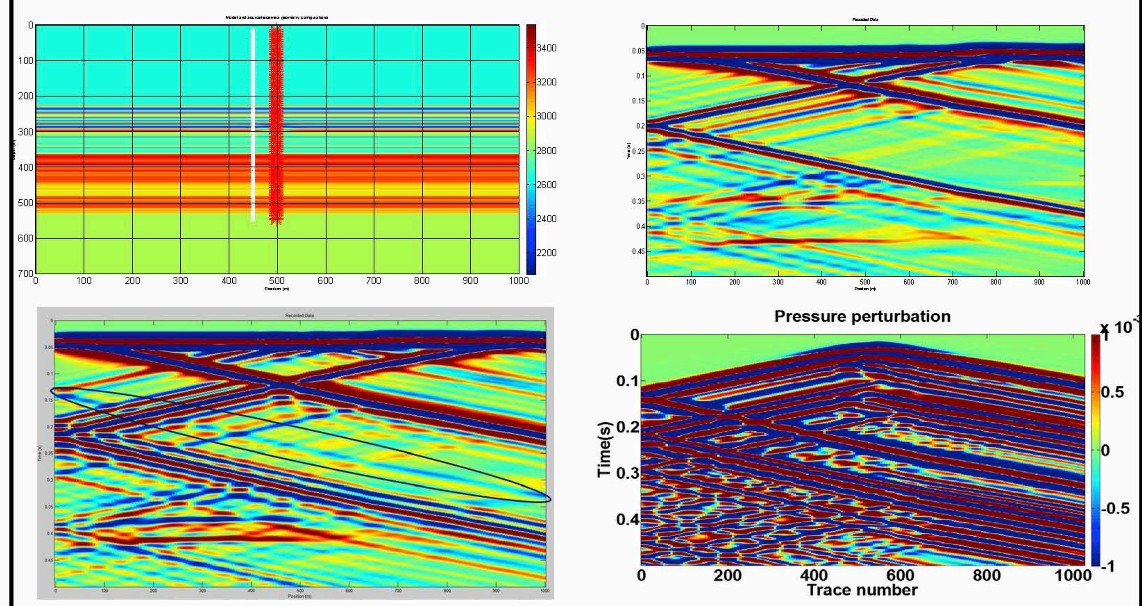

FIG.10.Acquisition result for the Crosswell acquisition. Top Left is demonstrated shots and recovers configuration (red : shots, white : receivers) Top Right is the result for the base seismic and bottom left is for after injection data and finally the difference between monitored and base data.

CONCLUSIONS

In the seismic modeling part, a single shot across the well with 1 km receivers spread and group interval of 3 m and a 2D line were modeled. In the baseline shot it is possible to recognize a remarkable change for the time lapse model. A difference of 2D model (base model-monitor model) was migrated and it reveled a realistic seismic change was observed. The study area has very simple layer-cake geology, dip angle of layers is less than two degrees, the surface is flat with no static problem and injection zone is in very shallow depth.

ACKNOWLEDGMENTS

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