Seismic modeling of CO_2 fluid substitution for the Heartland Area Redwater CO_2 Storage Project (HARP), Alberta, Canada

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ABSTRACT

The Devonian Redwater reef, northeast of Edmonton, Alberta, is being assessed for geological storage of CO_2 for the Heartland Area Redwater CO_2 Storage Project (HARP). It is located in the industrial Heartland area close to large sources of CO_2 in the Redwater-Fort Saskatchewan-Edmonton region. The reef complex is one of the largest Devonian reefs in the Western Canadian Sedimentary Basin (WCSB). It has a triangular shape with an area of about 600 km^2 and lies at depth of approximately 1000 m (-400 m elevation), and has a thickness of up to 300 m. The reef is of Devonian age and is made up of the Lower, Middle and Upper Leduc Formations. It is underlain by the Cooking Lake carbonate platform and overlain by the Ireton Shale which forms the caprock to the oil-bearing leg on the updip side of the reef as well as for the proposed CO_2 storage. A shale embayment occurs around some parts of the reef margin at the Mid-Leduc level.

In order to assess seismic monitoring potential for the CO_2 storage project, fluid substitution seismic modeling was undertaken. Gassmann fluid substitution modeling was undertaken using two on-reef wells which penetrated the Cooking Lake platform below the reef. Porosity of the Leduc Formation was calculated from the density logs and ranged from 4% to 6%. Synthetic seismograms were calculated from the log data before and after fluid substitution with supercritical CO_2 replacing brine. For the modeling, the temperature and pressure of the Leduc Fm were determined to be 34 degrees Celsius and 7.38 MPa respectively and the brine salinity was 107,000 mg/l TDS (Total Dissolved Solids). To create synthetic seismograms for these wells, P-wave, density, and S-wave logs were used. In this case, there is no S-wave log available. Therefore, the S-wave log was created using the average of global empirical equations for carbonates in WCSB, which uses a linear equation to relate S-wave and P-wave velocity. Since the in-situ fluid in the reservoir is the formation water, the density and bulk modulus of the formation water were calculated to be 1072 kg/m^3 and 2.8575 GPa respectively. Also, since the Leduc formation is carbonate reservoir, the density, bulk modulus, and shear modulus of calcite matrix were calculated to be 2736 kg/m^3, 78.96 GPa, and 33.65 GPa respectively.

Gassmann fluid substitution calculations were computed for the entire thickness of the Leduc Formation (over a depth range from 1086 to 1324 m) for both on-reef wells. A P-wave velocity decrease of 4% is predicted to occur between 0% to about 40% CO_2 saturation, assuming uniform CO_2 saturation. For CO_2 saturations above 40%, the P-wave velocity will increase slightly. In comparison, the S-wave velocity is calculated to increase almost linearly with CO_2 saturation by a maximum of 0.6%, yielding an increase in Vp/Vs of about 4.5%.

Seismic modeling was based on the changes in Leduc acoustic impedance predicted to occur between the wet in-situ reservoir and after replacement of pore fluids with supercritical CO_2.

From this modeling, a time delay of 4.3 ms is observed for reflections from the base of the Lower Leduc Formation, assuming that the entire reef interval has at least 40% CO_2 saturation.

An integrated surface seismic and vertical seismic profile time-lapse seismic program has been designed to monitor CO_2 injection for HARP, planned to start by 2011.