Assessment of a Carbonate Aquifer for CO_2 Geological Storage in the Wabamun Lake Area

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Introduction

A significant number of large CO_2 emitters are located in central Alberta, Canada, including four coal-fired power plants in the Wabamun Lake area (Figure 1), with cumulative annual emissions in the order of 30 Mt CO_2. To help industry and regulatory agencies in selecting and permitting sites for CO_2 storage, proper characterization is essential, covering the principal aspects of CO_2 storage: capacity, injectivity, and confinement. The sedimentary succession in the Wabamun Lake area southwest of Edmonton was identified as a potential CO_2 storage site because it would minimize transportation needs and costs from the large CO_2 sources in the vicinity. A wealth of data on stratigraphy and lithology, fluid compositions, rock properties, geothermal, geomechanical and pressure regimes was used to create and characterize a comprehensive three-dimensional model of the deep saline aquifers in the area that could be CO_2 storage targets. These have sufficient capacity to accept and store large volumes of supercritical CO_2 at the appropriate depth and are overlain by thick confining shale units. One of these targets, the Nisku Formation in the Devonian Winterburn Group, was chosen for a more detailed investigation and modelling of the injection and spread of CO_2 in the subsurface.

The detailed assessment of the Nisku aquifer includes the geological and hydrogeological characterization of the Devonian Nisku Formation, as well as two-phase flow modelling to evaluate the fate of injected CO_2. A potential injection site was chosen in the center of the study area, in the vicinity of the Keephills and Genesee power plants. Combined annual emissions of these two power plants are in the order of 12.5 Mt based on published 2004 data by Alberta Environment). For the purpose of modelling the CO_2 spread in the subsurface, 30 years of CO_2 injection were assumed.

Geological and Hydrogeological Characteristics of the Nisku Formation

The depth to the top of the Nisku Formation in the Wabamun Lake area ranges from less than 1600 m in the northeast to 2150 m in the southwest. The Nisku Formation was deposited at the edge of a carbonate shelf. From southeast to northwest, relatively pure platform carbonates change into interbedded limestone and shale of ramp and ultimatively basin slope characteristics (Figure 2). Incorporating permeability measurements from core with geophysical log signatures and the general lithofacies trend suggest that the ramp facies generally has higher permeability than the platform carbonates. This observation is supported by the fact that hydrocarbon reservoirs in similar settings south of the study area are mainly found in the ramp facies, which formed a “fairway” for hydrocarbon migration (Watts, 1987; Switzer et al., 1994).

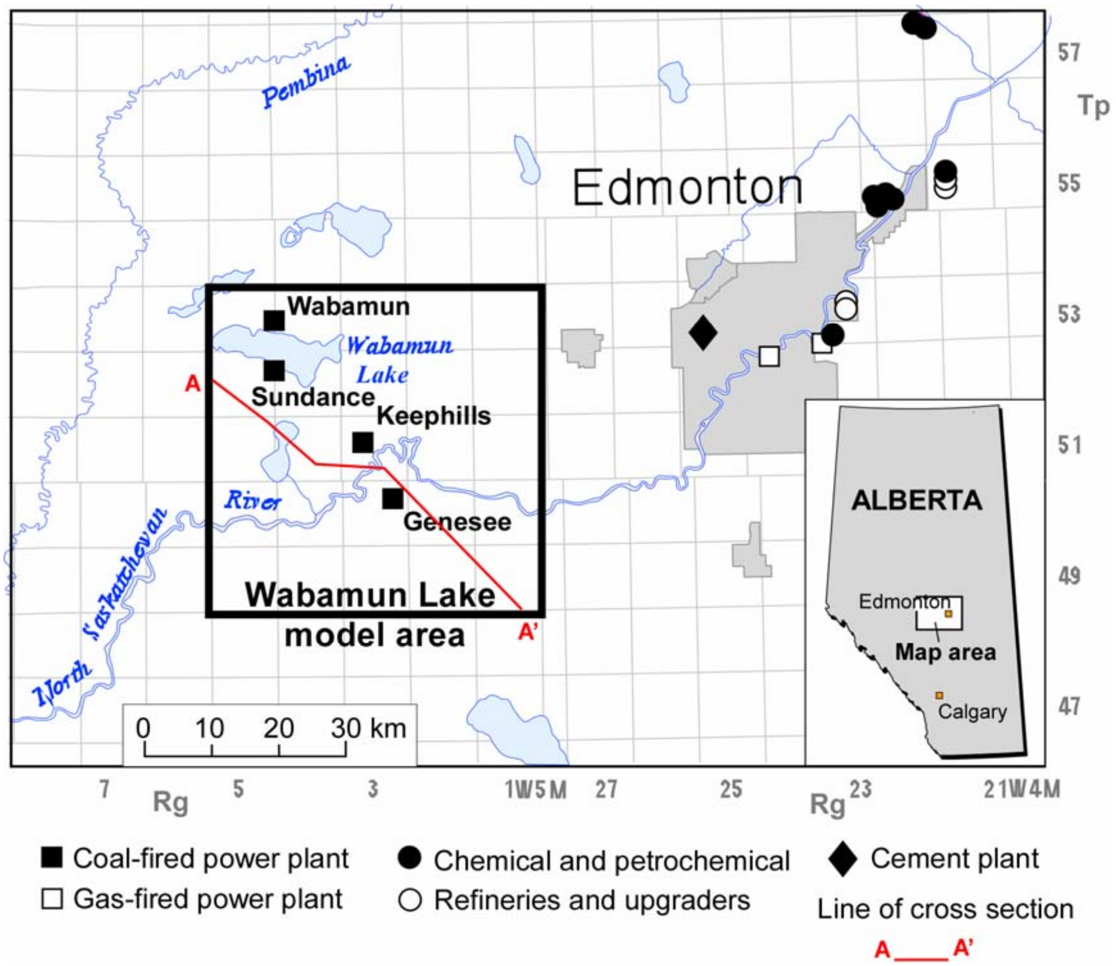

Figure 1. Location of the Wabamun Lake study area in Alberta, Canada, showing major CO2 emission sources.

The major constituents of Nisku formation water in the Wabamun Lake area are sodium and chloride, while calcium, magnesium, sulfate, and bicarbonate are present in minor concentrations. The salinity ranges between 138 g/l and 170 g/l. An average brine density of 1112 kg/m3 was calculated using regression expressions from measured data in the Alberta Basin and scaling to in-situ conditions (p = 15 MPa, T = 50.3 oC) (Adams and Bachu, 2002). The average in-situ viscosity of formation water is 0.75 Pa·s, and was calculated using relations for NaCl solutions (Kestin et al., 1978). In comparison, the CO$_2$ density and viscosity for the same in-situ p-T conditions, calculated according to Span and Wagner (1996), are 697 kg/m3 and 0.062 Pa·s, respectively. Relative permeability measurements of a Nisku carbonate sample run at in-situ conditions of pressure, temperature and water salinity indicate a relatively high value of 22 % for the residual CO_2 saturation and 50 % for the residual brine saturation (Bennion and Bachu, 2006).

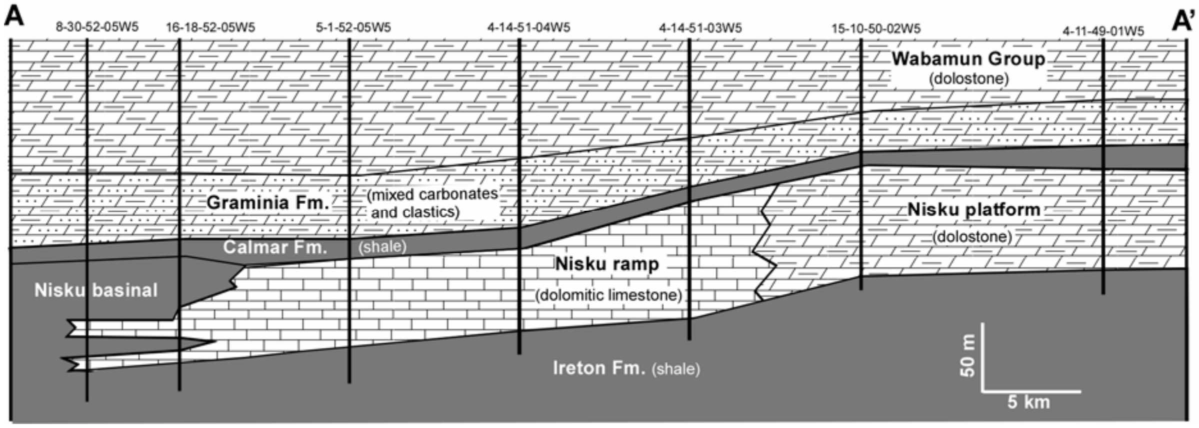

Figure 2. Strike cross-section showing facies change in the Nisku Formation in the Wabamun Lake area.

Numerical Flow Modelling

One-dimensional two-phase flow of CO_2 and brine, including the dissolution of CO_2 in formation water, was simulated for simplified flow geometry and medium properties using the STOMP (Subsurface Transport Over Multiple Phases) code (White and Oostrom, 2003). The injection of supercritical CO_2 into an infinite-acting horizontal radial domain was modelled for 5000 years. The porous medium was assumed to be homogeneous and isotropic, gravity and inertial effects as well as mineral reactions were neglected, and injection was simulated as 1-D radial (line source) at a constant mass rate. Under these still idealized conditions, the results show a 10 km radius of the CO_2 plume at cessation of injection after 30 years (Figure 3a). Approximately 16 % of the injected CO_2 are dissolved in the brine at this point in time. Pressures slowly dissipate over approximately 500 years to the pre-injection state, resulting in a maximum plume spread of 13 km. With the decrease in pressure, some of the dissolved CO_2 will come out of solution, leaving 14 % of the injected CO_2 dissolved in the formation water. Beyond 500 years, CO_2 concentration in the aquifer is at residual saturation and the CO_2 plume becomes immobile. As expected, the model is most sensitive to the value of residual saturation of CO_2 (S_{iC}). Just as an example, reducing S_{iC}, to 0.05 would result in lower average CO_2 saturations and in an increased maximum radius of the CO_2 plume by approximately 4 km.

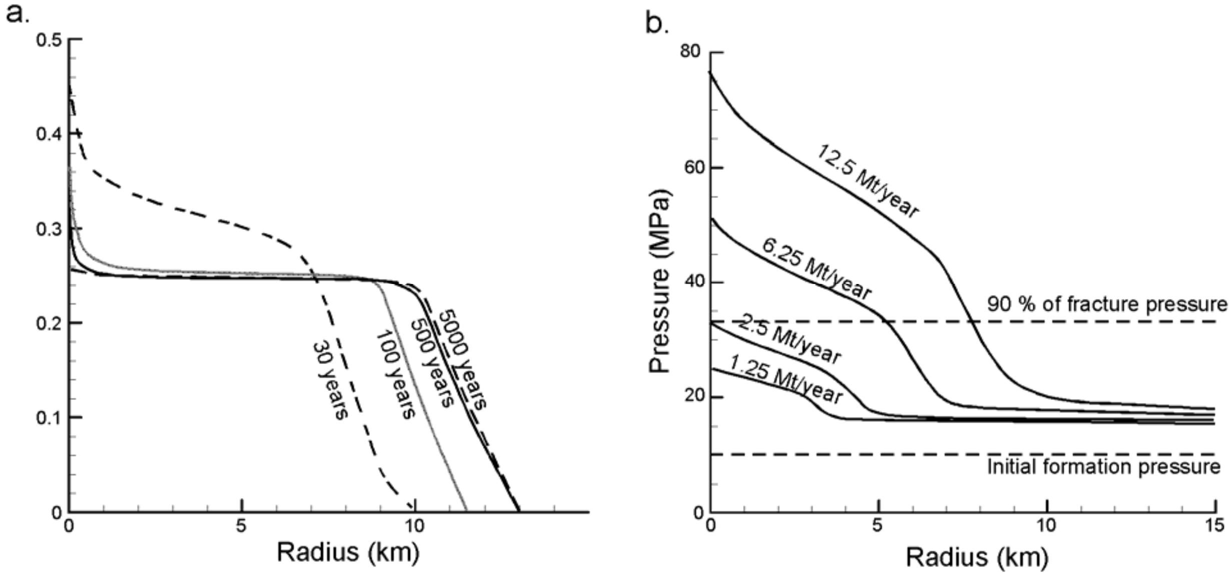

Figure 3. Results from one-dimensional, two-phase flow modelling with STOMP: a) radius of plume after 30, 100, 500 and 5000 years, and b) maximum bottom hole formation pressures for different injection rates.

Injection of CO_2 increases the pressure in the confined aquifer. According to current regulations in Alberta, maximum bottom-hole injection pressures have to be less than 90 % of the fracturing pressure of the injection unit to prevent the formation of fractures and the propagation of fractures from the aquifer into the cap rock. The fracture pressure at the top of the Nisku aquifer at the injection well (1810 m depth) is approximately 36.2 MPa, assuming a conservative gradient of 20 kPa/m. According to the model, the injection rate would have to be limited to less than 2.5 Mt/year (~80 kg/s) in order to keep the pressure in the aquifer below 32.6 MPa (90% of 36.2 MPa) (Figure 3b). Pressures decrease away from the injection well, such that at the end of CO_2 injection, pressures of 16 MPa (half of the threshold pressure) were computed 5 km away from the injection well. Consequently, at least 5 injection wells with a well spacing of 10 km would be needed to inject CO_2 at the required rate of 12.5 Mt/yr.

Conclusions

Favorable geological conditions, infrastructure and proximity to large stationary CO_2 sources make the Wabamun Lake area southwest of Edmonton a top candidate for implementation of CO_2 storage in deep saline aquifers. Comprehensive data holdings make possible a detailed study and characterization of this potential future CO_2 storage sites. Several deep saline aquifers are located at depths at which CO_2 can be stored as a supercritical, dense fluid. They are confined by several thick, low-permeability aquitards, preventing upward leakage of injected CO_2.

Initial modelling results suggest that the Devonian Nisku carbonate aquifer has sufficient capacity to accept CO_2 from coal power plants on the order of 12.5 Mt/year over 30 years. The lateral spread of the CO_2 plume in the subsurface would be limited to less than 15 km from the injection point due to dissolution of the CO_2 in the brine and CO_2 residual saturation. Multiple injection wells would be needed to inject this large amount of CO_2 to maintain bottom hole injection pressures below rock fracturing thresholds; hence injectivity rather than overall capacity will be the main limiting factor for the implementation of large-scale CO_2 storage.

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