Natural Barriers to Leakage from Potential CO_2 Storage Sites in the Redwater Area of Central Alberta, Canada: Geological and Hydrogeological Characterization

Tyler E. Hauck*
Tyler.Hauck@albertainnovates.ca

Dan Palombi*

Jesse Peterson*

and

Stefan Bachu*

*Alberta Innovates – Technology Futures, Edmonton, Alberta

Introduction

Canada's federal and provincial governments have announced significant financial support for the implementation of a number of large-scale CO_2 capture and storage (CCS) demonstration projects in western Canada. Funding has been in response to the recognition of CCS as an important component of worldwide strategies to reduce anthropogenic CO_2 emissions into the atmosphere, which have generally been accepted as a major contributor to climate change since the Industrial Revolution (IPCC, 2007). One of the demonstration projects that have received federal and provincial funding is the Heartland Area Redwater Project (HARP) that was initiated by ARC Resources Ltd. of Calgary. The HARP project is well-positioned to store several hundred megatonnes (Mt) of CO_2 captured from large stationary sources in the region of Alberta's Industrial Heartland (AIH), such as oil sands upgraders, refineries, fertilizer and chemical plants. The HARP project aims to develop and implement a pilot operation that, by 2012, will inject up to 100,000 t CO_2 into the water-saturated portion of the Redwater reef.

In addition to the Redwater Leduc reef, there are other deep saline aquifers in the Alberta Industrial Heartland area that are likely candidates to become storage targets. For example, the Basal Cambrian Sandstone (BCS) has been identified by Shell Canada Energy as a potential storage unit in the area northeast of Edmonton. A fundamental question in any storage project is the competency of the caprock that overlies the storage unit. Both the Redwater Leduc reef and the BCS are excellent potential CO_2 storage targets due to their favorable geological and hydrogeological setting. Both aquifers are directly overlain by competent shaley aquitards and numerous thick successions of shaley and evaporitic aquicludes that further provide secondary barriers to upward flow in this region of the Alberta Basin. Detailed regional geological mapping and hydrogeological analysis have been performed to determine the competency of the aquitards in the sedimentary succession that should form natural barriers to potential upward leakage of CO_2. The results of this geological mapping and the associated regional hydrogeological characterization are the focus of this presentation.

Methodology

Phase I of the HARP project, completed in the summer of 2009, consisted of an in-depth characterization of the primary storage unit (Redwater Leduc reef) and underlying Cooking Lake Formation based on existing subsurface data (core, wireline logs, VSPs). A comprehensive reef facies model based on core and a deterministic model of the Redwater reef and underlying Cooking Lake platform were produced for these two aquifers. The hydrogeological analysis focused on determination of the degree of hydraulic communication between the Redwater reef and the immediately overlying and underlying aquifers in the Woodbend and Winterburn groups. Mapping of the sedimentary succession was accomplished through the use of 557 well logs, 490 of which are located in a 5x4 township local-scale study area centered on the Redwater Leduc reef (Fig. 1). Wells outside the 5x4 township area were used for well control in Cambrian to lower Upper Devonian strata in which well penetrations are relatively few. Once formation tops were picked and verified through cross-sections, data were transferred into Petrel for the construction of a 3D mechanical earth model of the entire sedimentary succession in the local-scale study area, with the inclusion of the earlier model of the Redwater reef and underlying Cooking Lake Formation.

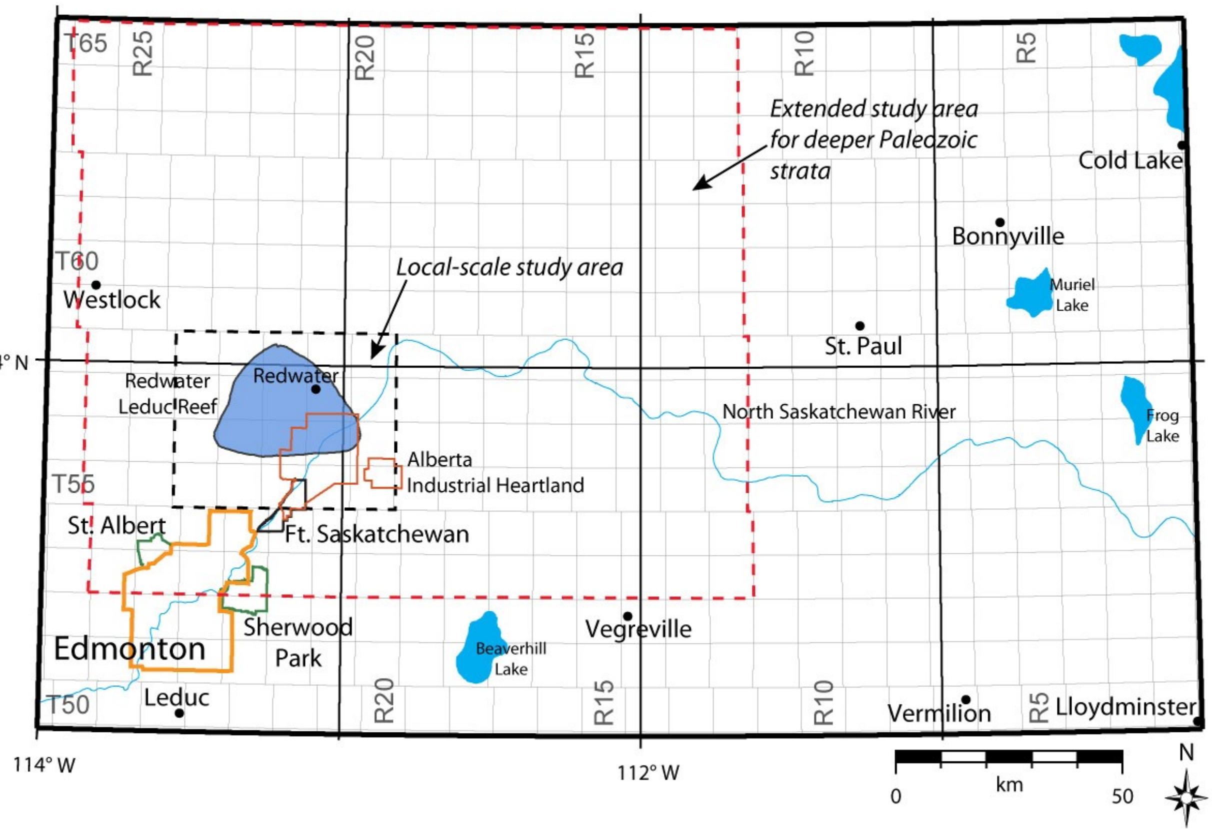

Figure 1: Study areas for the Heartland Area Redwater Project (HARP). Geological mapping of the sedimentary succession was done in the local-scale study area, and extended for formations from the lower Upper Devonian to the Precambrian basement due to scarce well penetrations. The regional-scale hydrogeology was analyzed at the scale of Figure 1, due to even scarcer information about formation waters. Note the proximity of the Alberta Industrial Heartland (AIH) to the primary CO_2 storage target (Redwater Leduc reef).

The hydrogeological characterization of the Paleozoic sedimentary succession was completed in a larger regional-scale study area covering much of east-central Alberta (Fig. 1) because of data scarcity. Using an updated hydrostratigraphic framework (Fig. 2), the hydrochemistry and hydrodynamics in the deep saline aquifers were interpreted using distributions of salinity and hydraulic heads, as well as the variation of major ions to define formation water chemistry and water types present. Distributions of hydraulic heads and graphs of pressure variation with depth were used to identify and analyze the lateral and vertical flow patterns and to assess the potential for hydraulic communication between aquifers and across intervening aquitards or aquicludes.

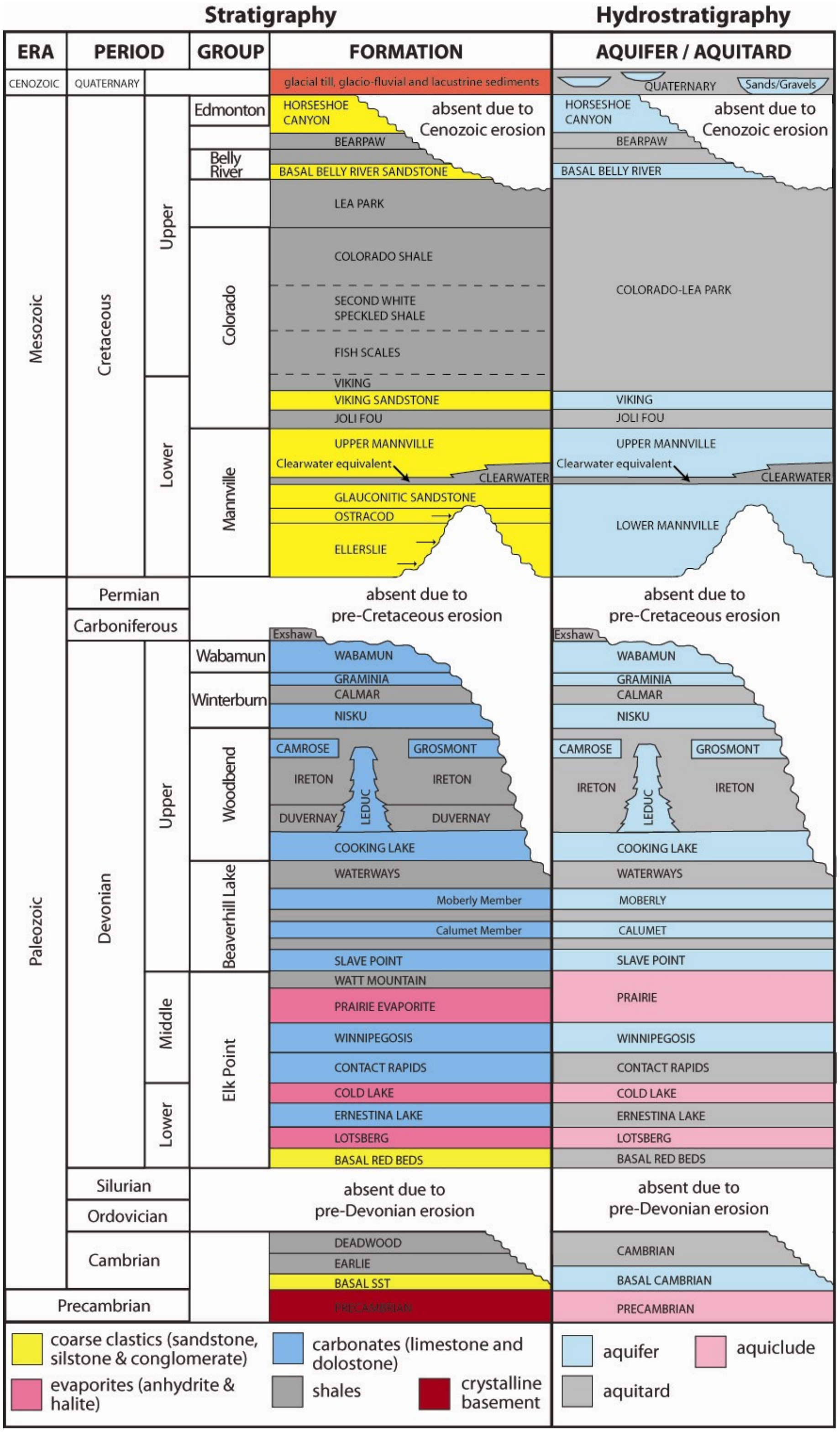

Figure 2: Litho- and hydrostratigraphy of the sedimentary succession in the Industrial Heartland Area of Alberta. The Paleozoic stratigraphy is represented at the regional-scale (Fig. 1). The Cold Lake, Camrose, Grosmont and Exshaw formations are absent in the local scale study area. The Mesozoic Clearwater Formation is thin or absent in the local scale study area.

Rock properties (porosity and directional permeability) for all the aquifers in the sedimentary succession were determined from all available conventional core analyses, and upscaled to well and field scales. Cored intervals were cross-checked with structural tops produced during mapping phases.

Results

The litho- and hydrostratigraphic column of Figure 2 is the result of geological mapping and hydrogeological characterization. The sedimentary succession has been delineated into hydrostratigraphy that reflects major or significant aquifer/aquitard groups.

Two deep saline aquifers have been characterized; 1) the Redwater Leduc reef, and 2) the Basal Cambrian Sandstone. The Devonian-aged Redwater reef is a large geological structure approximately 600 km^2 in area and more than 250 m thick, located at more than 1000 m depth. The reef initiated and grew on a topographic high of the Cooking Lake Fm. platform carbonates. Carbonate deposition ceased with rising sea level in the area, and the reef was eventually encased and capped by regressive shales of the Ireton Fm. Hydrogeological evidence indicates that the Redwater reef is in strong hydraulic communication with the underlying Cooking Lake Fm., supported by Leduc production-induced drawdown seen in hydraulic head distributions in the Cooking Lake aquifer and similarities in salinity distributions. In contrast, total dissolved solids (TDS) and hydraulic head distributions indicate the absence of hydraulic communication between the Redwater Leduc reef and the overlying Nisku aquifer. In addition, vertical pressure gradients indicate that there is no potential for vertical flow and that mildly downdip lateral flow predominates in the aquifers of the Woodbend and Winterburn groups.

The Basal Cambrian Sandstone (BCS) formed as near-shore sand sheets that unconformably onlap the Precambrian crystalline basement. The sandstones are inferred to have a marine origin, and their offshore-marine lateral equivalents (Earlie and Deadwood formations) eventually capped the sandstones (Dixon, 2008). Both the Earlie and the Deadwood formations are dominated by shales, and together with other overlying shales and evaporites of the Elk Point Group, form a competent caprock over the BCS in the study area. Evidence of this competency is recorded most strongly in formation water salinities in the BCS and the next overlying aquifer, the Winnipegosis. Measured salinities show a marked contrast between the two aquifers, and the analysis of major ion chemistry reveals that a Na-Cl water type is present in the BCS, versus a Ca-Cl water type in the Winnipegosis aquifer. Pressure-depth analysis also indicates that the Basal Cambrian aquifer is isolated from the Winnipegosis aquifer. The BCS is normally pressured and characterized by lateral updip flow, whereas the Winnipegosis aquifer is in a sub-hydrostatic pressure regime, with dense heavy brines being quasi-stagnant. Neither one of these aquifers exhibit potential for cross-formational flow indicating that the intervening aquitards and aquicludes, Earlie to Contact Rapids and the Prairie and Watt Mountain formations, are competent seals for the Basal Cambrian and Winnipegosis aquifers respectively (Fig. 2).

Other aquifers in the basin were mapped and characterized hydrogeologically, and include the Winnipegosis, Moberly Mbr. of the Waterways Fm., Camrose, Grosmont, Nisku, Graminia (Blue Ridge Mbr.), Wabamun, Lower Mannville, Upper Mannville, and Viking (Fig. 2). Comparison of aquifers separated by aquitards allows for determination of the degree of communication, or lack thereof, across the aquitards. Significant aquitards in the study area include the Cambrian to Contact Rapids, Prairie and Watt Mountain, most of Waterways, Calmar, Joli Fou, and Colorado-Lea Park succession. Two other natural barriers to potential upward leakage of CO_2 are the coal seams present in the Mannville and Belly River groups. Due to coal's adsorbent properties and higher affinity to CO_2 than to methane, any CO_2 that may reach these coal seams will likely adsorb onto the coal, thus preventing further migration and/or leakage.

Conclusions

Deep saline aquifers in the Industrial Heartland region of Alberta have the potential to store large amounts of CO_2 from large stationary sources in central and northeastern Alberta. Detailed geological mapping has delineated the position and geometry of aquifers and aquitards in the study area. Hydrogeological analysis indicates that there is a lack of hydraulic communication between primary Paleozoic storage targets and overlying aquifers as a result of the intervening competent shaley aquitards.

Acknowledgements

The primary corporate sponsor for HARP is ARC Resources Ltd. Government funders include the Alberta Energy Research Institute (AERI) and Natural Resources Canada. Other industry participants include Capital Power Corp. (formerly Epcor), Shell, Suncor, StatoilHydro, and Total E&P Canada. In-kind support was provided by Schlumberger.

References

IPCC (Intergovernmental Panel on Climate Change), 2007, Climate Change 2007: The Physical Science Basis: Fourth Assessment Report, IPPC Secretariat, Geneva, Switzerland.

Dixon, J., 2008, Stratigraphy and facies of Cambrian to Lower Ordovician strata in Saskatchewan: Bulletin of Canadian Petroleum Geology, 56, 93-117.