**AAPG/SEG/SPE HEDBERG CONFERENCE**
***"GEOLOGICAL CARBON SEQUESTRATION: PREDICTION AND VERIFICATION"***
**AUGUST 16-19, 2009 – VANCOUVER, BC, CANADA**

# The Wabamun Area $CO_2$ Sequestration Project: Challenges for Regional-scale Characterization of Deep Saline Aquifers

Jerry Jensen and Chris Eisinger
University of Calgary, Calgary, AB, Canada

The Wabamun Area $CO_2$ Sequestration Project (WASP) is a comprehensive characterization of large-scale $CO_2$ storage opportunities for an area southwest of Edmonton, Alberta (Fig. 1). As a benchmark, the project is examining the feasibility of storing 20 Mt-$CO_2$/year for a 50 year period. This gigaton-scale storage project is one to two orders of magnitude larger than the commercial projects now under study. It fills a gap between the province-wide capacity estimates (which lack site-specific studies of flow, geomechanics, etc.) and the detailed studies of smaller $CO_2$ storage projects currently underway.

Reservoir characterization integrates the available datasets and generates a quantitative, physically based model that can be used for targeting potential injection sites, simulating short- and long-term plume dynamics, identifying scenarios for $CO_2$ migration, and future, real-time monitoring of large scale, multi-site injections. For WASP, the target is the Devonian Nisku carbonate formation, a deep naturally saline aquifer regionally capped by the low permeability Calmar shale. Presented here are (1) the underlying conceptual geologic model for the regional Nisku, (2) an overview of the available datasets to be integrated, (3) and a discussion of challenges in modeling a system for large-scale injection. Our results suggest that:

1. The Nisku may be viable as a $CO_2$ storage aquifer, determined by the extent of higher porosity (>5%) and permeability (>300 mD) zones.
2. Understanding the highly heterogeneous nature of this regional carbonate remains an ongoing challenge of geomodeling efforts.
3. Adaptation of routine procedures applied in assessing and modeling oil and gas resources is needed for characterizing large-scale, sparsely measured saline aquifers. In particular, differences arise in several respects.
    a. Aquifer data availability and range of vintages create challenges in interpretation and reconciliation, especially over large areas of study.
    b. Increased attention to cap-rock integrity given the potential for fluid migration of $CO_2$ to overlying strata.
    c. Near-unity water saturations simplify petrophysical interpretation.
    d. Injectivity is paramount in $CO_2$ sequestration while porosity is less important.
    e. Much better understanding of the medium and large-scale (10's km) facies distributions is required.
    f. Seismic data must be acquired and processed on a much larger scale to be useful.

## Introduction

Possible injection formations within the WASP study area (Fig. 1) were assessed based on storage capacity, ease of injectivity, migration likelihood, and interference with current petroleum production. The Devonian Nisku appeared to be the best initial target interval and is the focus of current characterization work. Associated studies are aimed at evaluating how the injected $CO_2$ moves and reacts within the reservoir, the storage integrity of the over- and under-lying shaly aquitards (impermeable formations), the potential for $CO_2$ movement along existing wells, and preliminary injection well design.

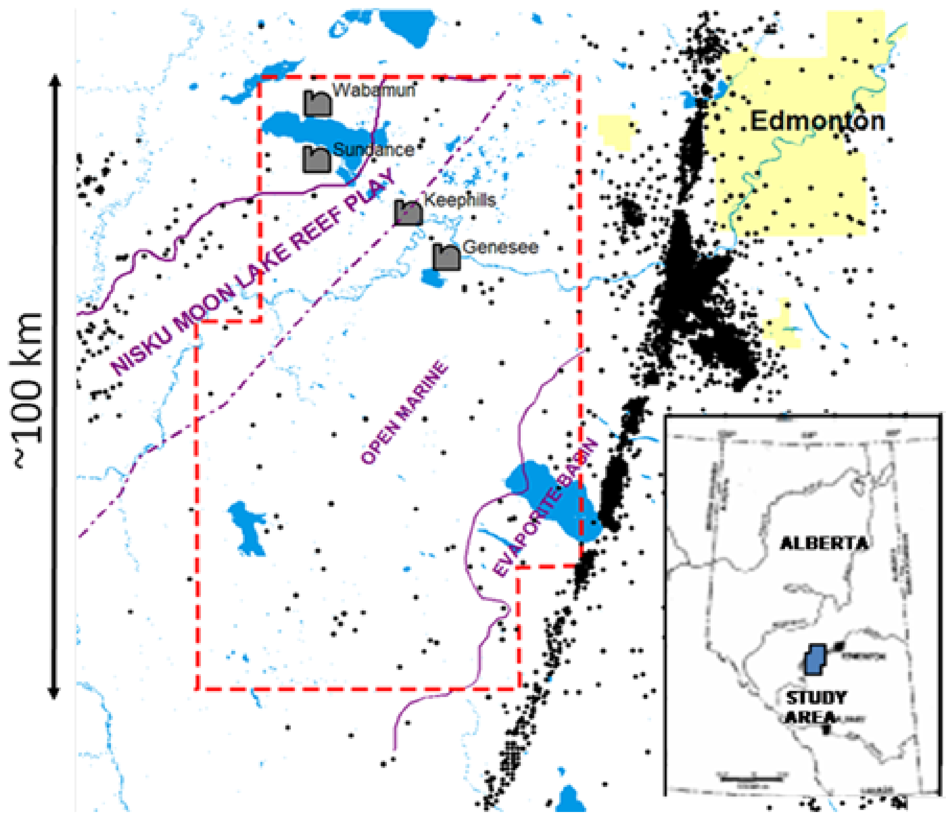


**Figure 1.** The WASP study area (red outline) and locations of four large power plants. Black dots show wells that penetrate the targeted stratigraphic interval. Solid purple lines mark important depositional boundaries of the Upper Devonian. The study area has an areal extent of approximately 5000 $km^2$.

## Geological Model

The Nisku was chosen because its depth, thickness (h), and stratigraphic configuration appear to be suited for $CO_2$ injection and storage. The targeted facies within the Nisku are dolomitized open marine carbonates showing localized porous zones with 6 to 15% porosity ($\phi$) and permeabilities (k) exceeding 300 mD. The extent of these zones is not well known due largely to a lack of quantitative geologic models for medium and large-scale (10's km) facies distributions.

Existing cores that penetrate the Nisku are limited in both lateral and vertical distributions throughout the WASP project area. Consequently, geological experience is required to estimate properties for portions of the target formation(s) that are lacking adequate data coverage.

## WASP Data & Static Model Framework

The static earth model comprises characterizations of facies and h, $\phi$, and k estimates in the WASP study area. The static model provides input for dynamic modeling of fluid flow and geomechanics. Information used for creation of the static earth model includes:

- Wireline geophysical logs (~80) of varying vintage, from the 1950's to recent suites.
- Drill stem tests (23) of fair-to-poor quality.
- Existing routine and special core analysis (5 wells), lithological descriptions of core, and newly acquired core analysis (8 wells).
- Petrographic studies, both publically available and newly completed for this study.
- Processed and raw geophysical data including 2D lines of varying age and a suite of recent 3D surveys (~200 $km^2$ total) covering approximately 4% of the entire study area.

A considerable effort was spent on quality control of data. From core- and log-identified formation boundaries, a stratigraphic framework was constructed. Integrating core, logs, and drill-stem tests provided $\phi$ and k estimates. The distribution of these data, however, present a challenge for accurate modelling in inter-well zones.

Modeling approaches included traditional geocelluar techniques, such as kriging and sequential guassian simulation. A more novel approach using Boolean objects to characterize high porosity and permeability zones was also employed. Results were used for simulating flow potential for a range of boundary conditions.

Our current models provide a guideline for potential injectivity, but do not yet provide an accuracy level which one would ideally like for initiating large-scale injection. The WASP project has allowed us the chance to identify the potential challenges for this project and other similar $CO_2$ injection projects planned or being investigated in western Canada and elsewhere.

## Reservoir Characterization - Injection into Deep Saline Aquifers

In the Western Canadian Sedimentary Basin, deep saline aquifers are attractive targets for large-scale injection of $CO_2$. Important characteristics include (1) high potential storage capacity (>4,000 Gt $CO_2$) and accessibility on a regional scale, (2) minimal likelihood for interference with hydrocarbon producing fields and plays, (3) utility of saline water in other capacities is limited or non-existent, and (4) saline aquifers are numerous in the region, occurring at a variety of stratigraphic intervals, which allows for flexibility in drilling and storage.

Geological characterization, however, is difficult. Most importantly, data are usually limited - cores sparse, wireline log data patchy or non-existent, and well spacings large. Seismic data, while perhaps locally available, is typically needed over a large areal extent to complete a thorough regional characterization. Access, processing, and interpretation of these large sets of data, if they exist, requires extensive time and financial resources.

Characterization for injection has other unique aspects that make the process different from production - emphasis is less on mapping exactly where the inject fluids go, but rather where potential leakage might occur; permeability pathways are arguably more critical in high-rate injection scenarios than for production where withdrawal rates are managed; and ownership of pore space may become a complex regulatory issue.

## Petrophysical Evaluation

Because of the large volume of aquifer and injection economics, connectivity is of greater importance than porosity. Porosity evaluation was further de-emphasized because of a lack of conventional porosity logs and the futility of using porosity to predict permeability.

We used electrical conductivity from wireline logs to predict both flow capacity (kh) and $\phi$. A correlation between electrical conductivity and well test kh and core kh values was exploited. Complete saturation of the aquifer with saline water allowed using Archie's relationship with a cementation exponent ranging between 2 and 3 to give viable $\phi$ estimates.

## WASP - Nisku Reservoir: Lessons Learned

Based on the WASP study, several general issues have emerged:

- Simplistic facies models are necessary due to data constraints. With limited core through the Nisku interval, characteristic facies were identified as either hypersaline or open marine. The most important distinction between these two facies was their potential flow capacities, which is reduced in the hypersaline facies due to anhydrite plugging.
- For petrophysical analysis, porosity and peremeability estimates were best made from available wireline resisitivity data. Acoustic logs, while usually available, appeared to underestimate the total porosity in the Nisku carbonates. The density-neutron logs gave better approximations, but were greatly limited in availability.
- Seismic data coverage provided a guide for populating properties over a limited subset of the total study area. Further, tying 2D seismic lines sets to acoustic wireline log data was difficult as wells coincident with coverage were rare. In the areas for which seismic 3D volumes exist, useful Nisku interpretations for building the model could be made.
- For characterizing the Nisku carbonate over a large area, with sparse data coverage, traditional geostatistical modeling approaches had limited utility. A better approach may be to incorporate conceptual geological knowledge in the form of plausible enhanced porosity objects. The geometry and distribution of these objects can be based on modern analogs or other comparable depositional sequences where parameters have been well quantified.

## Acknowledgements

This has been a collaborative effort with support from the entire WASP project team. We wish to acknowledge particular input from Frank Stoakes & Katrine Foellmer (SCG Ltd.Geology), Don Lawton & Abdullah Alshuhail (Geophysics), and Rob Lavoie (Project Management).

We are grateful to our project sponsors: Alberta Energy Research Institute (AERI), Natural Sciences and Engineering Research Council (NSERC), TransAlta, TransCanada, ARC Energy Trust, Penn West Energy Trust, Epcor, Enbridge, ConocoPhillips Canada, Encana, StatOilHydro Canada, Total Canada, Computer Modeling Group, and Golder Associates. We also thank Highpine Oil & Gas for sharing wireline log data.