



## Reservoir Characterization for the Wabamun Area CO<sub>2</sub> Sequestration Project: Geocellular and Boolean Modeling of a Regional-Scale Carbonate

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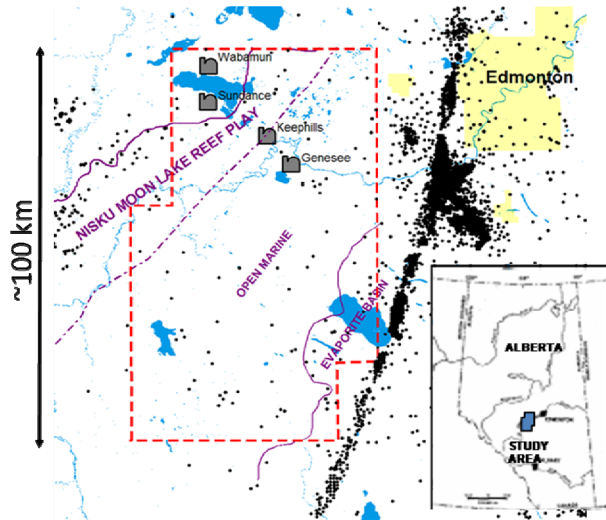
### Summary

The Wabamun Area CO<sub>2</sub> Sequestration Project (WASP) is a comprehensive characterization of large-scale CO<sub>2</sub> 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<sub>2</sub>/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 and geomechanics etc.) and the detailed commercial studies of smaller CO<sub>2</sub> 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<sub>2</sub> 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) the petrophysical and geostatistical modeling workflow, and (4) a discussion of geocellular and Boolean modeling approaches. Our results suggest the Nisku may be viable as a CO<sub>2</sub> storage aquifer, determined by the extent of higher porosity (>5%) and permeability (>300 mD) zones. Understanding the highly heterogenous nature of this regional carbonate, however, is the ongoing challenge in geomodeling efforts.

### Introduction

Geomodeling of any reservoir relies on the available input data (geological, geophysical, and reservoir engineering), the scales of system heterogeneity, and the degree of geological continuity for geostatistical analysis. A standard method used for characterizing oil and gas deposits was applied with some important adaptations for CO<sub>2</sub> injection: (1) the extensive size of the study area (Fig. 1) is much larger than typical oil and gas reservoirs; (2) the paucity of data over that large area - often kilometres separate existing well sites; (3) characterizing porosity and permeability for injection of CO<sub>2</sub> as supercritical fluid with the chief concern being maximum storage and not production; and (4) the potential for fluid migration to overlying strata, considering CO<sub>2</sub>'s buoyant nature.



**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<sup>2</sup>.

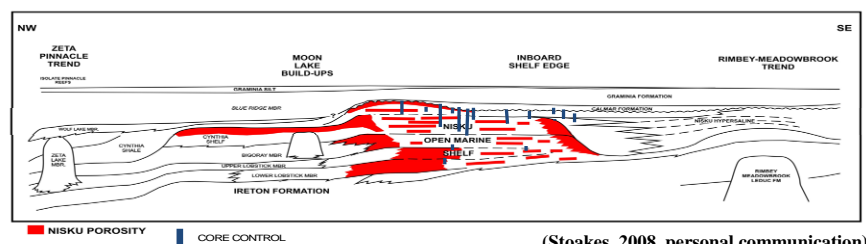
Possible injection formations within the WASP study area (Fig. 1) were assessed based on storage capacity, ease of injectivity, migration likelihood, and interference with current petroleum production. The Devonian Nisku appeared to be the best initial target interval and is the focus of current characterization work. Detailed studies are aimed at evaluating how the injected CO<sub>2</sub> moves and reacts within the reservoir, the storage integrity of the over- and under-lying shaly aquitards (impermeable formations), the potential for CO<sub>2</sub> movement along existing wells, and preliminary injection well design. All of these project goals will use the central earth model presented here.

### Geological Model

The Devonian Nisku was chosen because its depth, thickness, and stratigraphic configuration appear to be well suited for CO<sub>2</sub> injection and storage. The targeted facies within the Nisku are dolomitized open marine carbonates that show localized porous zones with 6 to 15% porosity ( $\phi$ ) and permeabilities ( $k$ ) in excess of 300 mD. The extent of these zones is not yet well defined however.

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 (Fig. 2).

**Figure 2.** A conceptual cross-section through the Nisku formation in the WASP study area. Red areas indicate higher expected porosity and vertical blue columns represent existing cored intervals. It appears that most cores are from relatively low porosity regions.



(Stoakes, 2008, personal communication)

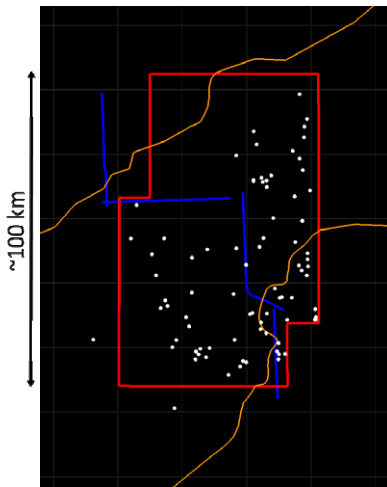
### WASP Data & Static Model Framework

The static earth model comprises characterizations of facies,  $\phi$ , and  $k$  in the WASP study area. The static model then feeds into dynamic models for fluid flow and geomechanical simulation. Information used for creation of the static earth model includes:

- Wireline geophysical logs of varying vintage, from the 1950's to recent suites.
- Drill stem tests of mixed quality.
- Existing routine and special core analysis, lithological descriptions of core, and newly acquired core analysis for 8 wells in the study area.

- Petrographic studies, both publically available and newly completed for this study.
- Processed and raw geophysical data.

The distribution of these data present a challenge for accurate modelling in inter-well zones (Fig 3).



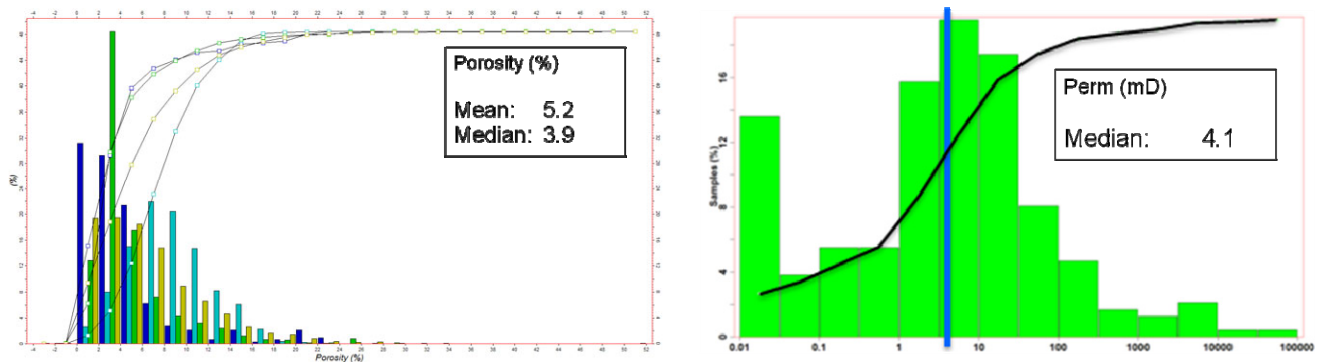
From core and log identified formation boundaries, a stratigraphic framework was constructed. A facies distinction between open marine and hypersaline/evaporite dominated carbonates (Fig. 2) was identified and mapped from core and log data. Flow boundaries are thought to be along northwest and southeast diagonals through the study area (Fig. 1). These were incorporated as edges of the effective reservoir boundary in the static and dynamic models (Fig. 3).

**Figure 3.** White circles show distribution of wells penetrating Nisku that are used for model generation. Blue lines show location of regional Lithoprobe seismic data. Orange lines represent the effective fluid flow boundaries of Nisku aquifer.

## Petrophysics & Geostatistics

Porosity estimates were made from core measurements and analyses of wireline logs (Fig. 4). Core measurements ranged from  $k < 0.1$  mD to  $> 1000$  mD (Fig. 4). A permeability predictor was developed for populating the entire gridded area, using porosity and resistivity (R) logs. Differences observed in core between the two depositional facies - open marine and hypersaline - are not as apparent in logs or measured  $\phi$ ,  $k$  values.

Various lithology plots suggest the majority of the Nisku in this region is dominated by dolomite with only minor occurrences of limy muds. Anhydrite observed in core is not easily recognized in most logs.

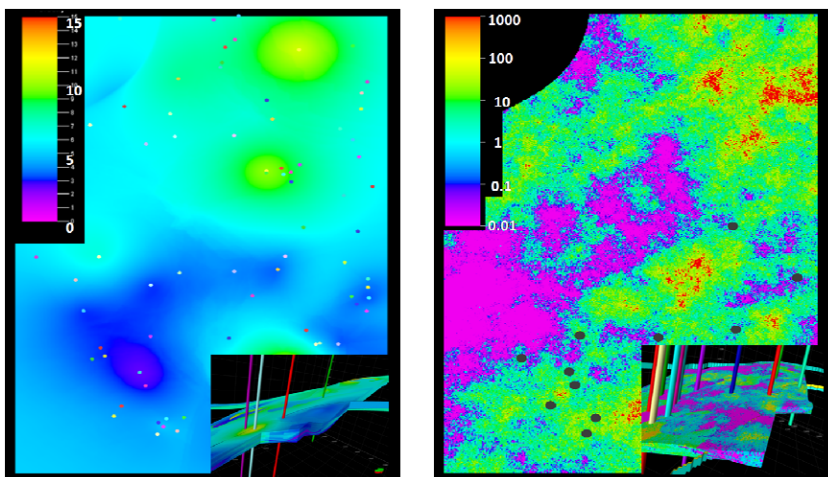


**Figure 4.** Multiple source porosity measurements (left) and core permeability estimates (right) for the Nisku aquifer open marine facies in the WASP study area. NPLS is the apparent neutron limestone porosity and Rhob is the density dolomite porosity.

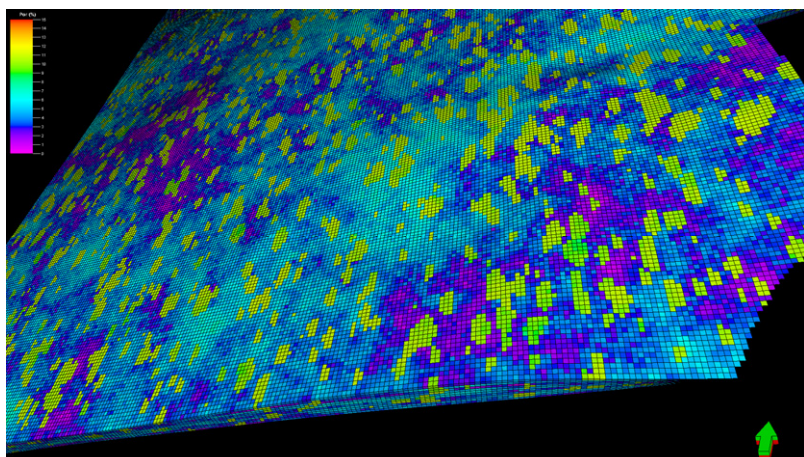
## Modeling

Two approaches are being tested to model the Nisku petrophysics. The first has  $\phi$  and  $k$  simulation by conventional geocellular methods;  $\phi$  is simulated using kriging (Fig.5) while  $k$  is estimated based on a  $\phi$ -- $k$ -- $R$  relationship using Sequential Gaussian Simulation (Fig 5). An additional step in the workflow relies on constraining the petrophysical model with seismic data. This is an approach commonly used for carbonate reservoirs.

**Figure 5.** Preliminary modeling of Nisku porosity (%) (left) and permeability (mD) (right).



The second approach is less common for carbonate reservoirs. A Boolean or object-based method is being used with variable geometric properties assigned to presumed moldic porosity zones (Fig. 6). In the upper Nisku, laterally extending and vertically constrained *Amphipora*-derived porosity bodies are being simulated. Considering the limited vertical and lateral distribution of existing petrophysical and geophysical data, building a Boolean model for the Nisku carbonates may be a more capable method for characterization of enhanced porosity regions. Standard stochastic modeling is unlikely to be sufficient to produce the full range of equiprobable realizations as it does not sufficiently incorporate uncertainties in our geologic understanding of the Nisku for this study.



**Figure 6.** Example of Boolean model output for open marine facies porosity distribution. Enhanced moldic porosity zones are modeled here as elongate ellipses and populated geostatistically using upscaled core and log porosities.

Geophysical attribute analysis can provide some constraints as to the the density and geometrical distribution of the enhanced porosity objects. Additional scenarios for these objects are being guided by conceptual models of carbonate ramp deposition and modern analogs.

### Acknowledgements

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