Object modeling for reservoir characterization in carbonates

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Summary

During the past 15 years, reservoir modeling methods based on objects have been developed and applied successfully (e.g. Deutsch & Wang, 1996; Holden et al., 1998; Hauge & Syversveen, 2003). A Boolean approach is generally better at integration of conceptual geologic information than traditional pixel-based methods using semivariograms. Variogram based methods struggle to accurately model reservoirs where depositional bodies and geologic shapes (which are typically curvilinear) control the distribution of flow properties (i.e. porosity and permeability). Fluvial reservoirs, characterized by a complex network of individual sand bodies, are hence well suited to object-based models (e.g. Holden et al., 1998). For carbonate systems, the application of object-based models has seen limited application, primarily due to the problem of defining carbonate depositional geometries and distributions and the impression that random, diagenetic influences are more important than depositional characteristics. Further challenges arise for Boolean methods with integration of denser well and 3D-seismic datasets (Strebelle & Levy, 2008).

An application of carbonate-object models is presented here with results and sensitivities associated with large-scale CO_2 injection. These are compared to more conventional pixel-based methods to estimate total storage capacity and injectivity. The role of object modeling is discussed in the context of regional saline aquifer characterization where data are sparse e.g., 1 well per 50 km^2. Results suggest object-based methods may be superior to pixel methods for geomodeling carbonates with limited well and seismic data.

Introduction

For this study, an object-based approach is used for regional characterization of a simplified carbonate deep saline aquifer. The Devonian Nisku Fm. of central Alberta is an attractive target for large-scale CO_2 sequestration due to its depth, porosity and permeability potential, and proximity to large-point source emitters (Fig. 1). As part of the Wabamun Area Sequestration project (WASP), well, core, and seismic data were acquired, quality controlled, and processed to build a static earth model for flow simulation.

The Nisku Fm. in this area is mudstone to packstone dominated with occasional occurrences of grainstone-dominated facies. The grainstone-dominated facies are the focus of our objects models as they provide the best injection and storage targets.

Efforts to apply traditional geocellular modeling produced results that poorly captured heterogeneity. Using sparse well distributions required speculative variogram analysis to predict facies, etc. for a large portion of the AOI (Fig. 1). The shapes of these facies distributions were not sharply defined and lacked plausible characteristics in the interwell regions. For example, along what would have been the inboard platform margin, pixel based methods produced unrealistically large enhanced poroperm regions (due to large lateral correlation lengths >5 km) with connectivity inaccurate. Thus an alternative approach was needed to better utilize available data.

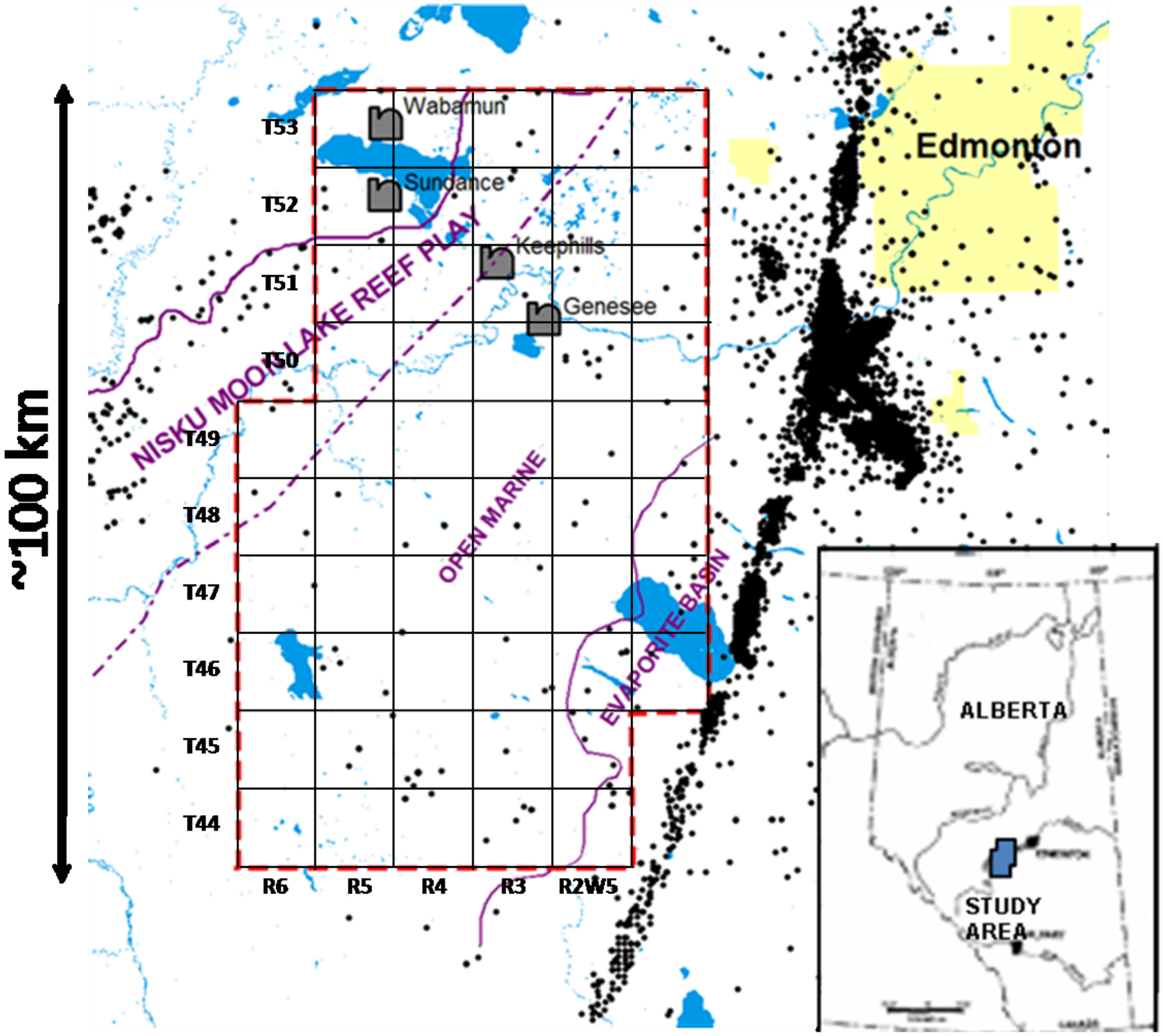

Figure 1: WASP study area (AOI red outline, ~5000 km^2) and locations of four power plants. Black circles indicate wells that penetrate Nisku Fm., and purple lines delineate depositional boundaries for carbonate platform during Upper Devonian.

Methods

The object geometry and distribution were characterized by using modern carbonate analog facies mapped from satellite imagery. For this study, work by Harris and Vlaswinkel (2008) was used to help select reasonable values for carbonate-object geometry and scale. The methods for classifying facies are described there. The analysis provides attribute data for reef associated facies obtained from platform groups based on shape and size (Harris and Vlaswinkel, 2008). Of particular interest are dimensions for partially aggraded reef and apron facies, which were likely to be a common depositional occurrence in the setting of the Nisku platform for the AOI (Table 1). Lateral distribution of these objects was subjective, based upon conceptual understandings of the Nisku Fm. carbonate platform in the WASP study area (Watts, 1987 and Stoakes, personal comm.). Two zones, or fairways, were imposed on the model (Fig. 2) to reflect a greater likelihood of higher porosity and permeability with better connectivity. One fairway corresponds with an area of likely reefal buildup along the inboard margin; another fairway represents the zone where the Open Marine is thickest - the result of periodic reef growth.

Enhanced Porosity Class		Min (m)	Mode (m)	Max (m)
Better	Orientation (Azimuth)	25	35	45
	Major Width	50	500	1200
	Maj/Min Ratio	1	5	7
	Thickness	0.5	5	10
Best	Orientation (Azimuth)	25	35	45
	Major Width	20	300	800
	Maj/Min Ratio	1	5	7
	Thickness	0.1	2	6

Table 1: Geometry of enhanced porosity and permeability objects. Distributions are triangular between min, mode, and max.

Porosities and permeabilities for objects were determined based on the distribution as determined from wireline conductivity measurements for two classes of enhanced porosity and permeability zones:

1) **Better** - porosity with normal distribution mean of 8%; permeability with log-normal distribution mean of 30 mD.

2) **Best** - porosity with normal distribution mean of 14%; permeability with log-normal distribution mean of 200 mD.

Sequential Gaussian simulation was used to predict the properties for the background carbonate mudstone facies. For both objects and background, modeled flow parameters were constrained to wireline log and seismic-based acoustic impedance data where available. Objects were modeled volumetrically for each vertical zone (upper, middle, and lower) and class (better and best) based on wireline data.

Systematic iterations of object distributions and volumes were generated, and each was then geostatistically populated for flow properties. Sensitivity analysis on flow simulations was performed. The final model outcome was a combination of strong geologic interpretation and traditional geostatistical methods constrained to available data.

Discussion

Some examples of object-based models for the regional Nisku Fm. are shown in Fig. 2. Shapes and distributions of higher porosity/permeability carbonate facies are simulated in these models. Using objects, we could easily keep the grainstone facies in limited areas, running in bands parallel to the paleoshoreline. We were not able to do this with the variogram-based methods. This experience is similar to that reported by Holden et al. (1998) in object modeling of a fluvial system.

An important question is whether these carbonate depositional features, on a regional scale such as the Nisku, are amenable to object constraints as used for fluvial systems i.e., do they have well defined boundaries? Are they curvilinear? Are there erosional rules that need to be observed? In many cases, the answer is yes, and this affects the applicability of method. In this study, we assumed no erosion and the objects (grainstone facies) have distinct boundaries.

For the modeled reservoir region of the Nisku Fm., models with up to 25% grainstone facies show an increased potential storage capacity of 10% above the pixel-based models. Injectivity volumes are also larger as connectivity is better captured in the objected based simulations.

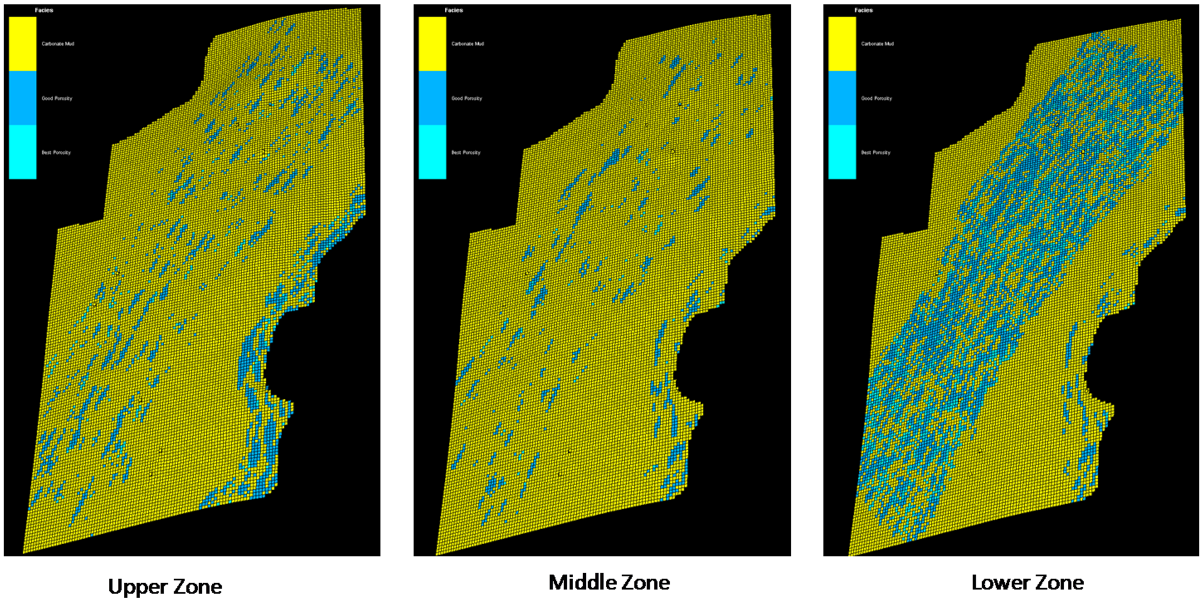

Figure 2: Example of object geometries and distributions for object-based modeling for three Nisku Fm. intervals in WASP area. Yellow - background carbonate mudstone facies; blue - better porosity and permeability objects; turquoise - best porosity and permeability objects.

Conclusions

Presented here is an application of object-based modeling to a regional carbonate system to better capture the heterogeneity of rock properties in the Nisku Fm. of central Alberta. Traditional, variogram-based methods, which have been the method of choice for carbonate systems, were not useful in modeling the Nisku, since there are few wells and they are sparsely located. Limitations in available object conditioning data for carbonates (i.e. outcrop and modern analog data) were addressed using information from new sources, including satellite remote sensing of modern analogues. The result was a model which captured the heterogeneity in a geologically sensible way and in which storativity and flow capacity are somewhat greater than in pixel models of the Nisku.

Acknowledgements

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