Quantification of Uncertainty in Gas Resources of Deep Panuke

DEUTSCH, CLAYTON, University of Alberta, Edmonton, Alberta; RICHARD WIERZBICKI, EnCana Corporation, Calgary, Alberta; ROBERT RIDDY, EnCana Corporation, Calgary, Alberta; and JOHN SLADE, EnCana Corporation, Calgary, Alberta;

Geostatistical tools have become widely used to construct reservoir models that realistically represent heterogeneity. Uncertainty is often calculated as a by-product of geostatistical modeling by generating multiple realizations. The significant uncertainty in the modeling parameters themselves must be accounted for also. We show uncertainty quantification applied to the Deep Panuke gas field which is located approximately 250 km southeast of Halifax, Nova Scotia, Canada. Deep Panuke is a reservoir within the Jurassic aged Abenaki carbonate platform that underlies the original Cretaceous Panuke oil field, Canada's first offshore project. The Abenaki IV and V stratigraphic cycles have a vertical thickness of about 200 m and an areal extent of about 3 km by 11 km. The majority of the gas is trapped in reservoir quality limestone and dolomite in the Abenaki V cycle

Uncertainty assessment requires much more than changing a random number seed and running multiple realizations. The space of uncertainty must be formulated to fairly address all key aspects of uncertainty. This space of uncertainty must be sampled. Each sample from the space of uncertainty is a complete specification of the reservoir geometry and internal structure, which can be visualized and evaluated for geological plausibility and all response variables such as in-place resources and recoverable reserves. Then, the results must be analyzed and presented to convey important results and sensitivities. We implement these three aspects of uncertainty management (1) problem formulation, (2) sampling uncertainty, and (3) analysis of results.

There are two exploration wells in the backreef and six exploration wells in the reef. The seismic data provided a 3-D model of three seismic derived lithotypes: (1) low porosity (less than about 10%), (2) vuggy limestone-type porosity, and (3) dolomite-type porosity. Seismic was also correlated to porosity. This presentation focuses on porosity and the GIP.

Problem Formulation
Our quantification of uncertainty is only as good as our problem formulation; no amount of experimental design and exhaustive computer runs will overcome a poor formulation in the first place. Our main focus is the first order sources of uncertainty that affect (1) the static petroleum resource and (2) heterogeneity as used by flow simulator. We are concerned with features that can be modeled at the geological modeling scale. Following is a list of the key variables and a brief description of how their uncertainty will be handled for Deep Panuke:

1. **Top structure** (top of the Abenaki V) has uncertainty away from the well locations due to (1) interpretation difficulties of the exact time at these surfaces, and (2) velocity uncertainty in the time-to-depth conversion. This uncertainty is addressed by "flexing" the base case constrained to zero deviations at the well locations. The base case surface comes from the latest interpretation from seismic data. The deviation from the base surface is modeled with a Gaussian histogram with standard deviation of 10 m in the backreef area and 30 m in the reef area; the additional uncertainty in the reef area is due to the effect on the seismic data of more complex geology in this area. The range of correlation of these deviations is 750 m. Following are four top structure maps (all units are meters). Two hundred were generated.

2. **Thickness** or the base of the Abenaki V also has uncertainty. The uncertainty is less than the top because uncertainty is in the interval interpretation and interval velocity. The base surface is flexed with the top surface and then the thickness is considered uncertain to account for the interval uncertainty. The thickness deviation is modeled with a Gaussian histogram with standard deviation of 2.5 m in the backreef and 5 m in the reef area. The range of correlation is 750 m. The deviations track those of the top structure shown above.

3. **Location of the backreef boundary** is the transition to poor quality Wackestone to mudstone-dominated limestone. A systematic translation of the base case backreef boundary will be considered. The uncertainty in the translation is considered to be uniform between −300 m to 300 m. This was chosen based on the change in seismic character from the backreef to the reef and the well locations where the backreef and reef are known. The sketch below shows the relative location of the backreef between the red lines.

4. **Backreef porosity** is uncertain based on the data from wells B-90 and F-09 in the backreef. There are limited reserves in the backreef; nevertheless, uncertainty in the backreef porosity is important and is modeled with multiple geostatistical realizations using data from the two wells in the backreef. The histogram of porosity is taken from these two backreef wells. The normalized variogram from the reef (see below) is also used in the backreef. Uncertainty in the histogram and other modeling parameters in the backreef are not deemed significant.

5. **Location of the back of backreef** is of some importance due to the modest reserves in the backreef. The back of backreef boundary is shown on the schematic above as the upper green line. This limit is approximately 3 km back from the backreef at the H-08 end and about 1 km back from the backreef at the M-79 end. The uncertainty is modeled by a translation that is uniform between −250 m to 250 m

6. **Porosity in the reef** is uncertain even with all geostatistical modeling parameters fixed. This uncertainty is quantified by generating alternative geostatistical realizations of porosity.

7. **Porosity histogram** within each of the three lithotypes is an important source of uncertainty given the limited number of well data. The most important aspect of this uncertainty is the mean or average value. The shape of the histograms will be kept the same as the original data within each lithotype. There are really only four wells in the reef (H-08, PP-3C, PI-1A/B, and M-79/A) with quite different average porosities within each lithotype.

Declustering is important to determine the representative average within each lithotype. Often, wells are drilled in areas of highest reservoir quality based on seismic data. Sometimes, the very best areas are avoided because of issues with well control. The seismic-derived lithotypes and the well data were used for declustering in Deep Panuke. The reservoir volume, of each lithotype, was used to weight the lithotype average near each well. The declustered average porosity increased in two lithotypes (1 and 3) and decreased in the second lithotype. There is significant uncertainty in the declustered average porosities given the limited number of wells. The shape of the distributions of uncertainty in the average value is Gaussian. This is expected from the central limit theorem of statistics and was confirmed by applying the bootstrap. The average porosity within each lithotype and the standard deviations: (1) average of 0.058, standard deviation of 0.023, (2) average of 0.127, standard deviation of 0.093, and (3) average of 0.134 and standard deviation of 0.046.

8. **Variograms of porosity** in the different lithotypes measure the spatial continuity of the porosity and have an important local effect on porosity and the gas resource. The base case from the available well data has a vertical range of 8 m, a horizontal anisotropy of 1.8 (greater continuity along the reef), and a horizontal range of 500 m, see the variograms below. Uncertainty in the horizontal range along the reef is modeled with a triangular distribution with a minimum of 100 m, mode of 500 m, and maximum of 1000 m; the 1.8 to 1 anisotropy is preserved.

The vertical and horizontal variograms are shown below. The areal trends cause a zonal anisotropy, a vertical trend causes the linear increase at large distances. The horizontal variograms are from seismic data. There are six sets of points: along the reef (dark points) and perpendicular to the main reef direction (light points) for the normal scores of the different seismic-derived porosity. The red and blue vertical arrows are to help establish the horizontal anisotropy.

9. **Correlation with seismic** (porosity within the lithotypes) is uncertain and is varied within reasonable bounds. A triangular distribution with a minimum of 0.5, mode of 0.65, and maximum of 0.80 is taken to apply at the small scale. Porosity will be modeled with sequential Gaussian simulation with collocated cokriging. The seismic data has an important

local control on the porosity distribution, but the rescaling of the seismic to a normal or Gaussian distribution removes any global influence of the seismic.

10. **Water saturation – porosity relationship** has a direct effect on the gas resource. The water saturation decrease with porosity. The availability of modern well logs and numerous capillary pressure measurements did not remove ambiguity in the S_w/ϕ relationship. A linear relationship with an endpoint at 0% porosity and 50% porosity was considered. The endpoint at 0 % is uniformly distributed between 0.2 and 0.4 and the endpoint at 50% is uniformly distributed between 0.05 and 0.2.

11. **Formation volume factor** converts from reservoir conditions to surface conditions is well known and yet uncertainty is modeled with a uniform distribution between +/- 2% of the measured value.

12. **Abenaki IV porosity** has some importance since a small part of the total resource sits in the IV, but it is mostly below the GWC. The porosity in the Abenaki IV is modeled with two runs of sequential Gaussian simulation: one for the reef and one for the backreef. The backreef boundary is taken from the Abenaki V.

Sampling Uncertainty
The preceding section described how we formulated the problem, that is, defined the uncertainty at Deep Panuke. This uncertainty must be sampled and processed through the transfer function (resource/reserve calculation) to quantify uncertainty in the output variables. A major consideration in this aspect of uncertainty assessment is the time required to generate realizations and process realizations. Great care and planning is required when these times are significant. In the case of GIP calculation, the time is not important. In the case of full field flow simulation, the time can be extraordinarily important and special steps such as realization ranking must be considered.

Sampling uncertainty requires generating many realizations. A *realization* is a complete specification of a reservoir, for example, the structure, lithotypes, porosity, and permeability. Questions arise about how to combine the different sources of uncertainty: should multiple porosity models be considered for each structure model? Should multiple permeability models be considered for each porosity model? The short answer is "no." True Monte Carlo simulation requires that each realization be constructed as a new random drawing from the "space of uncertainty." Generating multiple porosity realizations for a single facies realization would impart unwanted correlations between the "realizations."

A base case scenario, where all input variables are set at their expected values, is required. This is straightforward in conventional uncertainty analysis; however, there may be multiple runs required for the base case in geostatistical assessments of uncertainty. For example, in Deep Panuke there are multiple geostatistical realizations of porosity in the backreef, reef, and Abenaki IV even with all geostatistical modeling parameters frozen at their base case values. We built 20 base case realizations.

Then, each input variable can be varied one at a time. The response variables can be compared to the base case(s). This method gives the sensitivity of the response function to independent variations in the input parameters; the method does not give a full assessment of uncertainty. Nevertheless, this approach is robust and useful to establish the sensitivity of the response variables to each input variable. The P_{10} and P_{90} range, considering each variable separately, can be used to rank the sensitivity of each variable. For example, considering the GIP at Deep Panuke:

These tornado charts are sometimes constructed using the correlation coefficients between the input sources of uncertainty and the output variable.

Unlike the "vary one at a time" approach, a proper Monte Carlo Simulation MCS involves varying all variables simultaneously. The idea is to randomly draw values from each input distribution and then to evaluate the response variables of interest with the full set of simulated parameters. The drawing of each variable or parameter is done
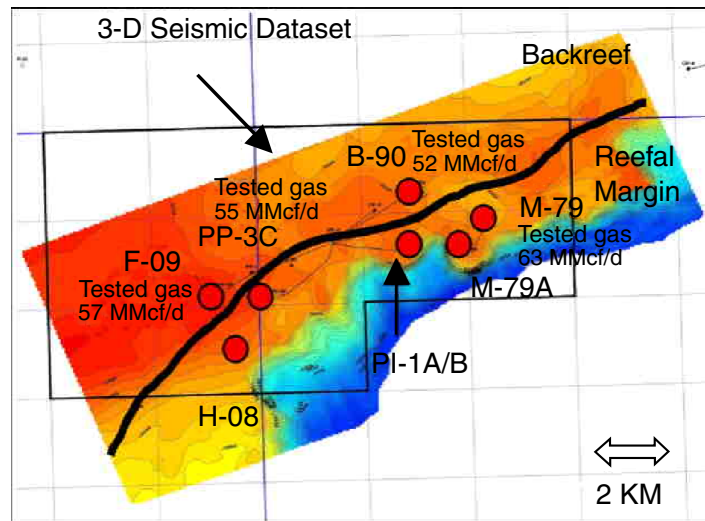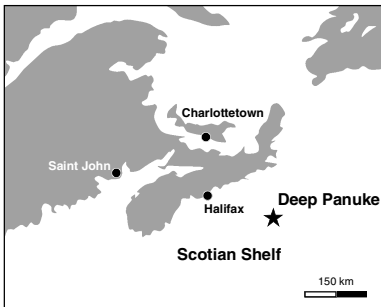
sequentially, that is, the variables are ordered and each j variable that is drawn is conditioned to the j-1 previous simulated values. This ensures that the simulated realization respects correlations between variables and is a plausible realization. Many realizations are generated and the response variables calculated for each to construct histograms of each response variable. These histograms inform the full space of uncertainty of the response variables. This very simple and powerful Monte Carlo Simulation works just fine if the problem is simple and there are few sources of uncertainty. Two hundred realizations were generated and distributions reported at various porosity cutoffs.

Conclusions
Uncertainty assessment must be approached with (1) a careful specification of important aspects of uncertainty, (2) a sampling of the space of uncertainty, and (3) a presentation and analysis of results that supports decision-making.

References
Deutsch, C.V., 2002, *Geostatistical Reservoir Modeling*, Oxford University Press, New York, NY, 376 pages.

Deep Panuke: Location Map; Abenaki V Structure Map,

Seismic and Well Locations, Backreef Boundary;

Stratigraphic Column.

Top Surface 01

Top Surface 02

Top Surface 03

Top Surface 04

Reef

Porosity Variogram - All/Reef

Vertical trend at large scale

Variability due to areal trends

Variability within each well (on average)

γ

Distance

Seismic

γ

Distance

Backreef Boundary											
Porosity Histogram											
Sw/Porosity Relation											
Porosity Realization											
Seismic Correlation											
Top Surface											
Variogram Range											
Abenaki IV											
Formation Volume Factor											
Backreef Porosity											
Back of Backreef											
Base Surface											