Integrated Static Model Uncertainty Analysis of the Lower Ben Nevis I Reservoir at the Hibernia Field

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Introduction

Although past evaluations of the Early Cretaceous Ben Nevis Avalon (BNA) sands at Hibernia Field have predicted very large volumes in place (STOOIP >1000 MM bbls), a 5 fault block waterflooding development into the pool has yet to fully meet production expectations. The waterflooding development which consists of 5 oil producing and 5 water injection wells has taught us a great deal about the risk elements and key uncertainties associated with the nature of the BNA reservoirs.

Key static uncertainty parameters for the BNA include: fault compartmentalization, reservoir facies proportions, spatial distribution and presence of sand, reservoir quality, reservoir heterogeneity and connectivity. Well placement and well trajectory are now seen as critical to ensuring good injection rates and good connection between oil producers and water injectors in the discontinuous BNA reservoirs.

Objective

This study presents a fit-for-purpose workflow whose main objectives are the assessment of probabilistic STOOIP and static connectivity. Another objective is the quantification of the key static model uncertainties on both volume and connectivity. A benefit of this structured and practical workflow is that it provides an un-biased way to select P_{10}, P_{50} and P_{90} geologic models based on oil in place and static connectivity as ranking criteria. Furthermore, these three geologic models will be the inputs to reservoir simulation and will be used to assess reservoir performance under different development scenarios.

Case Study

We present a case study that is focoused on the Lower Ben Nevis I (LNB1) section located in the central BNA area of the Hibernia field.

A geocellular model that comprises 6 major fault blocks is iteratively built using the following applications: GOCAD for geologic modeling, VOXELGEO for seismic horizon and fault interpretation and PETREL for stratigraphic analysis as well as for well log display. These tasks involve interpretation, integration and reconciliation of subsurface data.

Previous studies have indicated that fault compartmentalization is one of the key uncertainty parameters that impact fluid flow performance in BNA reservoirs. Consequently, 7 major bounding faults and 15 internal block faults are incorporated into the geocellular model. Many small scale faults could not be incorporated into the model due to modeling constraints. These small scale faults can be clearly detected using the amplitude extraction and visualization capabilities of VOXELGEO. The effect of these small faults should not be neglected because they have proven to act as baffles during production.They are accounted for in the reservoir simulation stage.

The LBN1 section is divided into 4 units. Hence, the faulted stratigraphic grid is divided into 4 zones to capture the unique characteristics of each sequence. These sequences are composed of reservoirs interpreted as a tidal channels deposited in an estuarine environment oriented NNW-SSE. Reservoirs are relatively thin, vertically heterogeneous with a generally poor correlation between wells. Model cell dimension is designed as 25m in the horizontal dimension and 0.5m on average in the vertical.

The first objective of next step is to generate High, Base and Low geologic scenarios.

A six log “depo-petro” facies model is generated for each well as conditioning data for the geological model. Facies are populated in 3D using Chevron’s proprietary Multi-Point Statistical (MPS) simulation capability added to GOCAD. This technique includes the following input data and external constraints:

- The correlation of low amplitude anomaly strength indicates the presence of reservoir facies. Hence, a “Facies Probability Cube” is generated as a “soft” 3D constraint on the spatial facies distribution.
- A vertical “Facies Proportion Curve” is used to constrain the vertical distribution and the resultant stacking pattern of facies.
- Net to Gross is provided through “Regional Facies Proportions” for each of the 4 sequences.
- Depositional environment information is included in a three dimensional stratigraphic grid called a “Training Image”. This grid is generated using the facies body relative dimensions and shapes, as well as associations between each of the six facies types.

Porosity is populated by facies using Sequential Gaussian Simulation (SGS) based on well data external histograms and variograms for each facies. Permeability is then populated by facies using Sequential Gaussian Simulation with a collocated co-Kriging conditioning with porosity. Water saturation is populated based on the “Flow Zone Indicator” (FZI) equation.

Finally, STOOIP and static connectivity is calculated for each of the end member cases (Low and High) as well as for the base case. Static connectivity is defined as the volume of the larger geobody for grid cells with permeabilites greater than 100 mD. At this stage of the analysis we do not know where these cases fall on the probability distribution curve.

The next step is to generate a probabilistic STOOIP and to evaluate the impact of static model uncertainties on STOOIP and connectivity. The objective of this task is to select P10, P50 and P90 geologic models based STOOIP and static connectivity, two ranking criteria that will be used later to perform fluid flow simulation and economics. We use the Plakett-Burman Experimental Design (ED) method and Monte Carlo Simulation that are part Chevron's Uncertainty Workflow plug-in to GOCAD.

The ED table is composed of 6 independent variables (uncertainty parameters) and 2 dependent variables or outputs (ranking parameter criteria). The independent variables that impact STOOIP and static connectivity are the following: 1. Training image (depositional environment), 2. Regional facies proportion (NTG), 3. Porosity histogram (Porosity uncertainty), 4. Porosity variogram (three dimensional distribution), 5. Permeability histogram (Permeability uncertainty), and 6. Permeability variogram (three dimensional distribution). Water saturation (Sw) is considered as dependent to the permeability histogram variable.

The ED method tells us we have to build 8 different geologic models to adequately capture uncertainty without running hundreds of realizations. The independent variables can only take either Low or High as values. Each model has a specific combination of those variables dictated by the Plackett-Burman design. A ninth geologic model is constructed, but in this case each independent variable takes the base case values. This case is considered as a reference to compare to the ED analysis and to understand any inherent bias. The outputs are two linear polynomial equations (for STOOIP and Static connectivity) that are a function of each of the 6 independent variables. Next we assign a distribution to each of the variables and run Monte Carlo simulations with the 2 equations.

The final step is to select P10, P50 and P90 based on the two output ranking criteria: STOOIP and static connectivity. Pareto Charts show the relative significance of independent variables to STOOIP and static connectivity. In this case study, facies proportions (NTG) is the main uncertainty parameter that impacts both STOOIP and static connectivity. Sw (dependent on permeability) is a secondary uncertainty parameter that impacts STOOIP.

Summary and Conclusions

- A facies probability cube is generated by calibrating seismic amplitudes to reservoir facies proportions. Low amplitudes correlate to high reservoir facies proportions and consequently to NTG. They are used to constrain the orientation and spatial distribution of reservoir facies.

- The low amplitude anomaly distribution suggests the presence of the two reservoir facies throughout the study area. However, the anomaly strength fades towards the South-Southeast suggesting a progressively lower proportion of reservoir facies to the same direction.

- Some of the blocks are highly compartmentalized by small-scale faults as illustrated by the orientation of amplitude anomalies and by the use of visualization techniques.

- The good injection of well B16-52A supporting well B16_23 is because no faulting separates the injector from the producer and because of the presence of reservoir facies in the main producing interval (LBN1_2). Another factor that has contributed to the better injectivity of well B16-52A (currently at about 700 m3/d) compared to well B16-32 is that the former has been perforated in all sands with an improved perforating technique (TCP: Tubing Conveyed Perforation) compared to the later.
- The base case STOOIP is biased to the low side of the P50 probabilistic distribution, i.e. the Monte Carlo simulated Plackett-Burman result.
- Facies proportion (NTG) is the dominant uncertainty impacting STOOIP and static connectivity.
- The fit-for-purpose workflow provides a structured, un-biased way to select P10, P50 and P90 geologic models based on oil in place and static connectivity as ranking criteria.

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