Predicting Permeability from Core-to-Field – A Multi-Scale Geologic Modeling and Upscaling Workflow

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Abstract

Predicting geologically consistent permeability distributions is a major challenge in building 3-D reservoir models for production forecasting and reservoir management, because it is not possible to measure permeability data at the reservoir grid scale. In a conventional workflow, permeability values in reservoir cells along well paths, the so-called "conditioning data", are obtained by upscaling well log data. Permeability values between wells are derived through geostatistical methods. In this workflow, several fundamental assumptions are not valid in deriving the "conditioning data". First, permeability that is derived from a porosity log is based on permeability-porosity correlations that are established from core measurements. This correlation can be highly scale-dependent, unless the reservoir rocks are homogeneous across scales. Second, only the absolute permeability values are obtained from the correlation. The underlying assumption is that permeability is isotropic within cells in a geomodel grid, hence the impact of smaller geological features on fluid flow is completely ignored.

We have developed a new workflow to predict permeability from core through to the full field model without the above assumptions. The new workflow is based on a bottom-up approach, from the sub-millimeter lamina scale to tens of meters at the seismic data scale. We use a process-oriented method to simulate the geologic features that are too small to be represented in a full field reservoir model, such as the laminations, bedding structures, sand-body geometries, and shale drapes in channel infill architecture. Numerical simulation of fluid flow is then applied to the small geologic models at each scale. The upscsaling results from the smaller scale model provides the input to the next immediate scale model, therefore making it possible to predict effective permeability from core measurements through to a full-field reservoir model, without simplifying the geologic reality of the reservoir.

We illustrate the multi-scale modeling and upscaling workflow in a channelized reservoir model. At the core scale, the input is the permeability data that is measured at the lamina scale. The heterogeneity model at the core scale is built from sedimentary bedding structure processes. Directional permeability is upscaled from the bedding model, which then provides the input to the channel infill architecture model. The third scale model is the conventional geocellular model built from seismic interpretation or well correlations. Upscaling of the third scale model provides the input to the production simulation model. Since heterogeneities at multiple scales are modeled and upscaled step-by-step, the effective permeability provided to the full-field production simulation can capture fluid flow impacts at the sub-grid scale. Compared with conventional workflow that ignores sub-grid scale heterogeneity, we demonstrate that a multi-scale modeling and upscaling workflow not only results in geologically consistent permeability models, but also improves the forecasting of production rates and recovery factors, thereby reducing uncertainty in reservoir management.