APPLICATION NOTE

Multi-scale heterogeneity modeling - A method for reservoir data integration

Introduction

Reservoir heterogeneity exists at multiple scales, from pore structures to bedding structures, litho-facies, and fault blocks. An ongoing challenge in conventional reservoir modeling workflows is to integrate multi-scale geological heterogeneity into reservoir models for the purpose of evaluating large-scale reservoir performance.

What follows is a modeling and upscaling approach to integrate reservoir data representing multiple grid scales. The approach focuses on generating 3D sub-seismic-scale (< 10 m) stratigraphic heterogeneity models for flow simulation.The original small-scale modeling approach was developed in order to model the heterogeneity at bedding structure scales (Wen et al., 1998), which bridges the scale gaps in core data and well log data. The modeling approach can be summarized as having three principal aspects: Process-oriented, rule-based and stochastically formulated. The process-oriented modeling (POM) method generates geological models by mimicking the physical processes behind sedimentary bedding, such as bedform migration, erosion and deposition.The approach formulates deterministic geological processes in a stochastic framework, thus combining advantages of both deterministic and stochastic modeling methods.

Method

The heterogeneity modeling workflow begins with a conceptual interpretation of reservoir geology based on core and outcrop observations, and seismic interpretation. A high-resolution grid is generated based on geological processes, and conditioned by a seismic interpretation framework grid. The grid is then populated with corresponding petrophysical data and upscaled by numerical simulation methods. The upscaled models reflect the effective properties of the rocks and can be calibrated to well logs and seismic data. Near well-bore models (e.g., Figure 1) simulated with the process-oriented modeling method can be used to improve the estimation of petrophysical properties from well log data and core data. Case studies demonstrate that this geological modeling approach can be used to estimate facies-dependent permeability anisotropy, such as kv/kh in heterolithic reservoirs (Elfenbein et al., 2005; Nordhal et al., 2005, Ringrose et al., 2003; Ringrose et al., 2005; Ruvo et al., 2005).

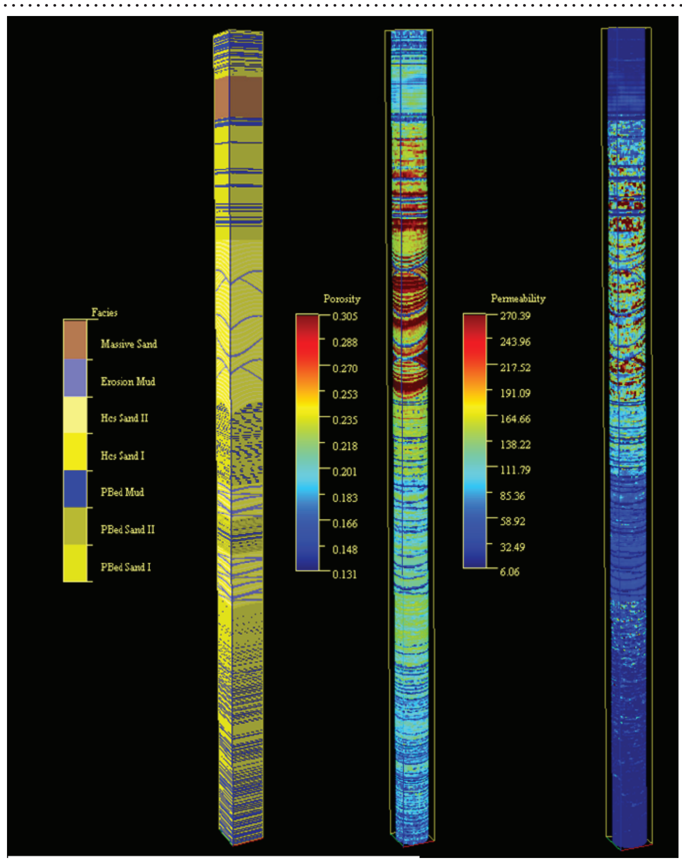

Figure 1
A near well bore model generated with bedding structure modeling software, SBED™. Such models have successfully been used to estimate kv/kh from very heterolithic reservoirs.

Small-scale heterogeneity modeling at bedding structure scale

The major feature of geological heterogeneity at the centimetre scale is the sedimentary bedding structure. Spatial distribution of rock properties such as porosity and permeability are largely controlled by bedding geometry, even for rocks that have undergone strong diagenesis. The bedding-structure-scale heterogeneity modeling method is a three-step process.

In the first step, a 3D bedding geometrical grid is generated by a process-oriented simulation algorithm (Wen et al., 1998), in which the deposition, migration and erosion of the bedform are modeled based on geological principles. In the second step, rock properties, such as porosity and permeability on each bedform are generated by the sequential Gaussian process, where trend in both horizontal and vertical direction can be introduced. The last step is the upscaling of rock property grids. Porosity grids are upscaled by arithmetic averaging. Permeability grids are upscaled by applying different boundary conditions, such as fixed, linear, and periodic upscaling. The two-phase upscaling and water saturation upscaling can also be applied.

Small-scale heterogeneity modeling at geo-object infill scales

The original process-oriented method has been applied to simulate larger scale geological models, such channel infill architectures, depositional lobes, and barforms. Object-based modeling methods are conventionally used to generate geobodies that mimic depositional structures such as channels, lobes and bars. Inside those geobodies, petrophysical values are simulated by statistical distribution, which assumes that no geological heterogeneity exists inside these genetic sedimentary units. The assumption may be acceptable for volumetric estimation, but it does not provide adequate detail for modeling fluid flow inside these bodies. Lateral accretion and metre-scale cross-stratification are often observed in channel sands and lobe deposits because of their formation processes. Using the same approach for simulating bedding structures at centimetre scale, we have developed simulation algorithms to generate detailed geometrical grids representing internal stratification and large-scale cross bedding in point bars, tidal bars, and lobes.

Depending on the objects to be simulated, the parameterization and simulation process is different. For example, for point-bar deposits, a surface at initial channel incision time is created, then the surface parameters are varied as the surface is deposited, migrated and eroded. The end results are a geometrical grid that captures the major genetic features in the point bar and a facies grid controlled by stratigraphic position. Rock property grids, such as porosity and permeability grids, are then simulated using similar methods to the existing geostatistical methods, using upscaling statistics from bedding structure models.

The resulting models more realistically represent reservoir heterogeneity in terms of fluid flow properties. These new developments provide modeling methodology to bridge the scale gaps between well log data and seismic data. More realistic uncertainty estimates can be obtained from this type of modeling (Barton et al., 2003). Simulations of stratigraphic features at sub-seismic scales, i.e. < ~10 m, (Figure 2) can also be applied to the interpretation of seismic attributes (Wen, 2005).

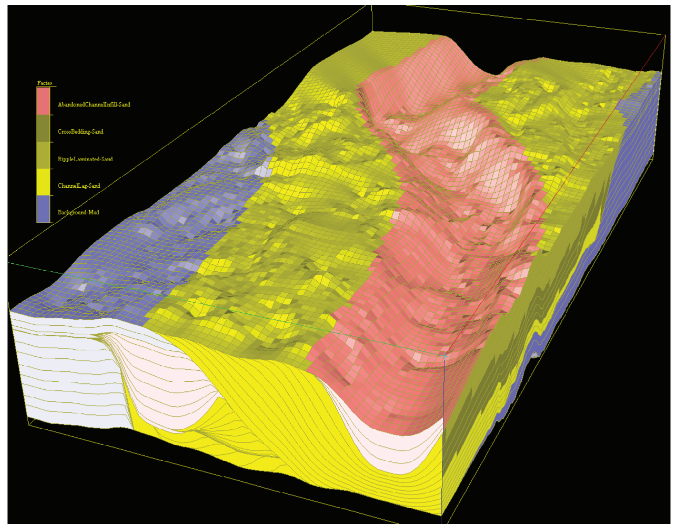

Figure 2.
A reservoir-scale geological model that includes sub-seismic-scal stratigraphic surfaces generated with SBEDStudio™. Channel infills are not represented by objects, but by stratigraphic layering, thus making it possible to represent important flow barriers, such as shale drapes.

Upscaling

Upscaling in conventional workflows is the process of coarsening reservoir geo-grids to the scale of simulation grids because the reservoir flow simulator cannot handle a large number of grid cells. This type of upscaling usually involves a scale change of 50 x 50 x 1 metre to 200 x 200 x 10 metres.

In our heterogeneity modeling approach, upscaling of small-scale geological models derives representative properties for evaluating reservoir flow properties (saturation, porosity and absolute and relative permeability) at a larger scale. The upscaled results are input to reservoir geo-grid property simulations. The change of scale in upscaling is 1 x 1 x 1 centimetre to 50 x 50 x 1 metre – about five orders of magnitude.

This direct upscaling of reservoir properties from both bedding structure models and sub-seismic stratigraphic models allows geologists and reservoir engineers to evaluate distribution of flow properties from all possible geological scenarios. By considering multi-scale heterogeneity, reservoir asset teams can integrate reservoir data more effectively and improve the prediction of reserve volumes and production profiles.

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