

# Multi-Scale Permeability Modeling and Upscaling Workflow Integrating Core, Well Log, Seismic Attributes and Geologic Models

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## Summary

Permeability is a critical reservoir property for evaluating reservoir production potential and recoverable reserves. However, it is very challenge to predict the spatial distribution of permeability in reservoir, even with many well controls, because the permeability is highly sensitive to reservoir heterogeneity. Permeability data measured from core plugs are not representative of the reservoir property at even slightly larger support volume, such as a rock volume that corresponds to a sample in well log or a seismic trace. We present a multi-scale modeling and multi-step upscaling workflow to predict effective for static reservoir modeling. The workflow derives directional permeability from smaller scale heterogeneity models through flow-based upscaling. Together with information obtained from well logs and seismic attributes, the multi-scale modeling and upscaling workflow result directional permeability grids ( $K_x$ ,  $K_y$ ,  $K_z$ ) that can reduce uncertainty in reservoir management.

## Introduction

Most static reservoir models built so far in the oil industry failed to reproduce production history without artificially adjusting permeability values in the reservoir static model, leaving a large uncertainty in reservoir simulation results. Among major uncertainties in the static model is the permeability, which has even larger uncertainty than other model parameters. The prevailing method of permeability modeling is based on a few underlying assumptions that are not valid at the large support volumes. In this paper we present a new workflow that derive effective permeability models in static reservoir model. The new workflow consists of two major components: the first component is building realistic geologic heterogeneity model at several distinctive scales to bridge the gaps in samplings and sample bias; the second component is upscaling smaller scale models into the size required by the next scale model. The workflow can be started from pore-scale measurement or digital rock modeling results, up to flow simulation at full field size through several steps (Figure 1), depending on the depositional environment of reservoir rocks. The multi-scale modeling and upscaling workflow will be illustrated in a fluvial reservoir example.

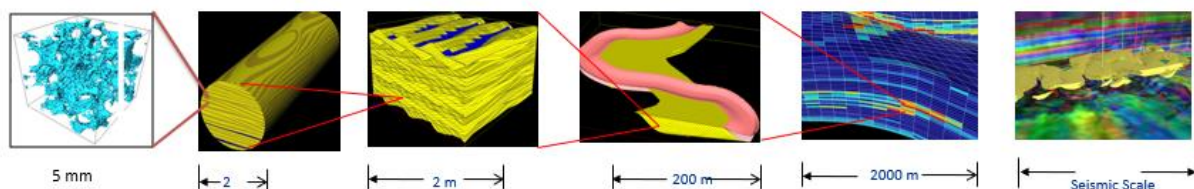


Figure 1. Multi-scale modeling and upscaling workflow. Data collected at small scales, such as core measurements, can only be used as used as input the heterogeneity model at the sampling scale because of heterogeneity within and between different spatial scales. Upscaling results from smaller scales can then be used as input to the larger scale modeling.

## Method and Workflow

The multi-scale modeling and upscaling workflow consists five steps:

**Step 1:** Make a stratigraphic grid based on seismic horizons and well tops. The stratigraphic layering below the resolution limit of seismic data can be generated from a process-oriented modeling method (Wen, 2005) or based on simple rules such as proportional, top or bottom conformable relationships.

**Step 2:** Assign litho-facies code to the stratigraphic model. Seismic attributes can be used to derive the facies grids by applying supervised or unsupervised classification (Wen, 2011). The lithofacies or genetic unit interpretation at the well location must be honoured.

**Step 3:** Build bedding-scale heterogeneity model in each lithofacies, based on SBED bedding model templates (Wen, 1999; Nordahl et al, 2011; Ringrose et al., 2011) and core interpretation. The porosity and permeability grids of the bedding scale model can be generated from statistics of core plug measurements conditioned on well data

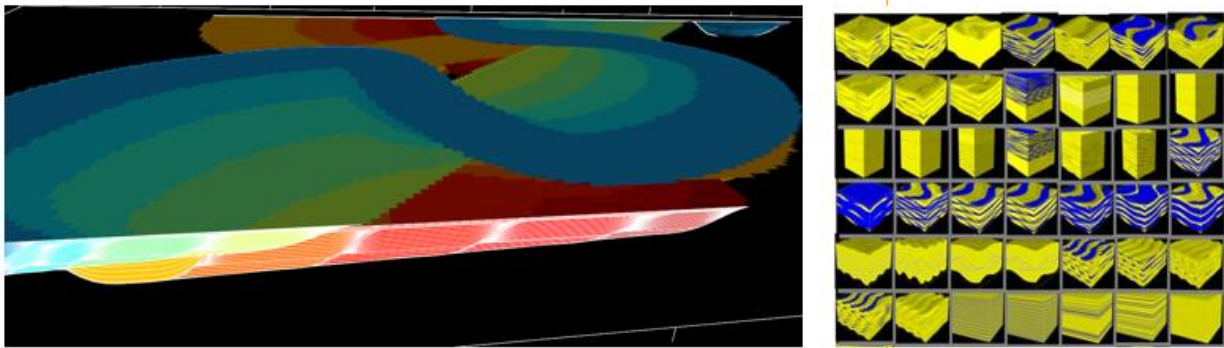


Figure 2. Geologic heterogeneity model templates at two scales: a) stratigraphic unit; b) lithofacies. Well log and core data can be used to determine vertical boundaries of stratigraphic unit and lithofacies. Seismic attributes, calibrated with well data, can be used to map spatial distribution of stratigraphic unit.

**Step 4:** Estimate statistics of effective permeability ( $K_x$ ,  $K_y$ ,  $K_z$ ) from flow-based upscaling of bedding structure models and genetic unit models, such as point bars, for each lithofacies or genetic units (Nordahl et al, 2014).

**Step 5:** Apply the statistics of directional permeability in different facies to the facies grids derived in step 2, resulting the  $K_x$ ,  $K_y$ , and  $K_z$  grids that can be further upscaled to a flow grid in the conventional reservoir simulation workflow.

The key difference in the above workflow with the conventional workflow lies in the steps 3 and 4, whereas the conventional workflow relies on a process of “scale up well logs” and assuming a porosity-permeability or similar correlation to derive permeability data at well locations.

## Examples

Figure 3 illustrate results from applying the multi-scale modeling and upscaling workflow to a fluvial reservoir. The facies model is obtained from seismic facies classification through a neural network method. The attributes we used include impedance inversion and spectral decomposition attributes. Kx, Ky, and Kz grids are simulated from statistics estimated from upscaling results in the bedding models of each facies.

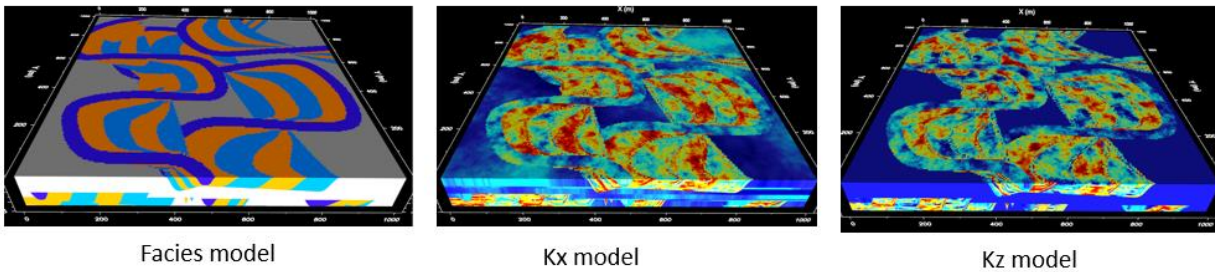


Figure 3. Lithofacies and directional permeability (Kx, Kz) grids derived from multiple scale modeling and upscaling workflow.

## Conclusion

The following conclusions can be made based on results from applying multi-scale modeling and upscaling workflow,

- 1) The porosity-permeability relationship and reservoir property distribution statistics are scale dependent. The porosity-permeability relationship obtained from core plug measurements cannot be used directly in the static reservoir model. Statistics from well log or core plug data are quite different from those in the static model, because of sub-cell heterogeneity and several orders of difference in support volumes. In general, the variance from well log derived statistics is too large to be used in the property modeling of static model.
- 2) Heterogeneity modeling and upscaling at the core-plug scale has a big impact to the uncertainty in the static model. For most reservoir, it is not valid to assume isotropic permeability at the scale of static reservoir model. Statistics of Kx, Ky, Kz derived from smaller scale heterogeneity models of each facies at the sub-cell scale can be used to populate the larger scale static models.
- 3) When data collected at different scales, such as core, well log and seismic attributes, are to be integrated for reservoir characterization, heterogeneity at each scale must be explicitly modeled in separate steps.

## References

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