

# SBED

## UPSCALING FROM CORE SCALE TO RESERVOIR GRID

### OVERVIEW

SBED software effectively integrates core and well log data into large-scale reservoir grid cells with a geomodel-based upscaling approach. The software builds high-resolution, near-well-bore models that capture small-scale bedding geometry and facies associations observed in well data, core descriptions, borehole images and dipmeter logs. When the models are populated with petrophysical data and upscaled to reservoir grid cell size, the resulting simulations generate realistic effective properties (porosity,  $k_x$ ,  $k_y$ ,  $k_h$ ,  $k_z$ ,  $k_v/k_h$ , NTG) for input to reservoir simulators.

SBED helps to identify net pay below the level of conventional petrophysical logs, adding significant volumes to estimated reserves associated with thin-bed sands or shale-dominated basin settings. It also provides critical input to simulations associated with improved oil recovery, such as SAGD projects.

### SBED UPSCALING WORKFLOW

- Create a 3D grid that simulates bedding geometries based on sedimentary processes.
- Populate the geometry grid with rock properties such as porosity, permeability and rock type.
- Upscale petrophysical grids to generate facies-dependent effective property values for input to large scale reservoir simulators.

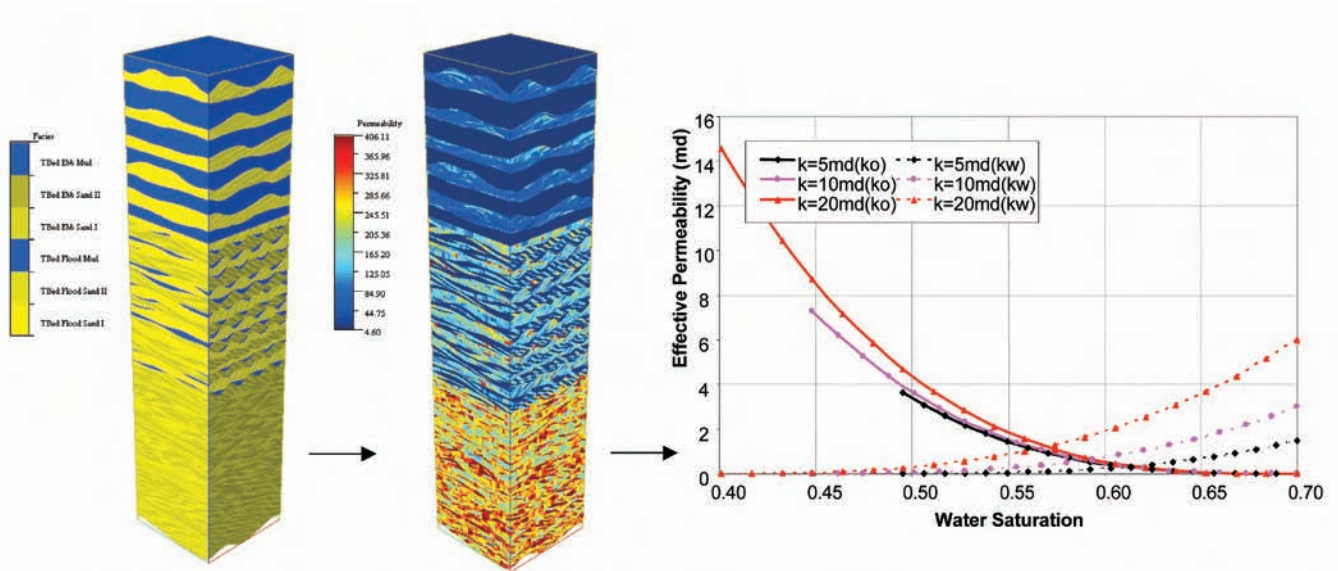


Figure 1. With SBED you can derive accurate, facies-dependent effective porosity and permeability distributions to reduce modeling uncertainty. Permeability barriers associated with small-scale sedimentary structures can significantly reduce flow capacity at relatively low levels of water saturation. In the above model, at  $S_w = .45$ ,  $k_0$  permeability at 20 md is reduced to an effective  $k_0$  of only 8 md.

Raw data such as permeability estimates from core plugs represent a single point within the well bore. Because the data are biased with respect to sample location, they do not adequately represent the actual conditions within flow units. Furthermore, the data are not available to the reservoir simulator.

SBED provides the ability to create petrophysical realizations from multiple sources and to integrate that data into representative stochastic models. Equipped with three upscaling modules (moving window, single-phase and multi-phase upscaling), SBED allows users to better evaluate reservoir quality and the associated uncertainties.

## MOVING WINDOW UPSCALING

Moving Window Upscaling provides type curves of petrophysical properties in the form of a standard well log. The resulting curves can be plotted against the well log and lithology descriptions to illustrate the effect of bedding geometry on petrophysical properties.

In SBED, flow-simulation-based upscaling is applied to an Irregular and Regular grid to derive effective porosity and permeability properties in the X, Y and Z directions. The upscaling calculation is made within a user-specified window area of a specific model. After the upscaling is calculated for the first window, the window is assigned a user-specified step-length, moved to a new location and then upscaling calculations are repeated for the new window. This process is conducted from a user-specified start to end position.

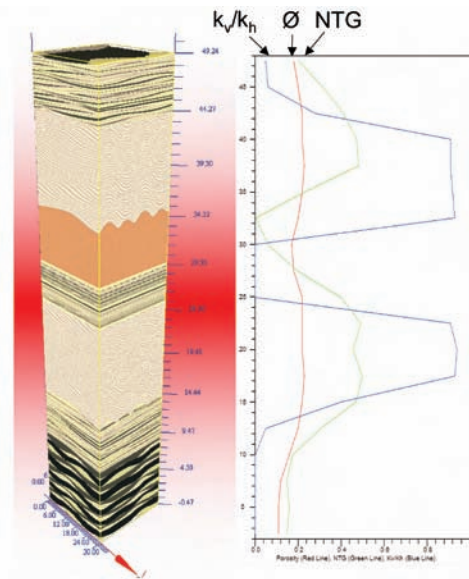


Figure 2. Type curves generated from an SBED stacked model: red line=porosity, green line=net-to-gross, blue line=  $k_v/k_h$  distribution. Note the thinly bedded silt and shale sequence separating two massive sands in the stacked SBED model. Rigorous definition of permeability distributions can highlight potential barriers to fluid flow which could critically impact IOR.

## MULTI-PHASE UPSCALING

Multi-Phase Upscaling generates relative permeability curves for multiple fluid phases. The relationship between the upscaled permeability values and facies associations help to define more accurate production profiles and better recovery strategies.

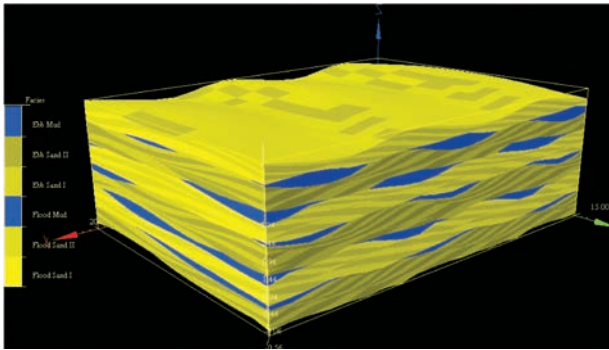
- Generate relative permeability curves based on three flow modes:
  - Capillary flow
  - Capillary and gravity-dependent flow
  - Viscosity-dependent flow
- Calculate water saturation curves for a given facies using two functions:
  - Ideal Water-Wet Capillary Equilibrium: Capillary pressure reflects the interaction of rock and fluids, and is controlled by the pore geometry, interfacial tension and wettability.
  - J-Function: A dimensionless capillary pressure correlation function.
- Run Multi-Phase Upscaling on up to 10 individual SBED models at once for faster reservoir evaluation.

## SINGLE-PHASE UPSCALING

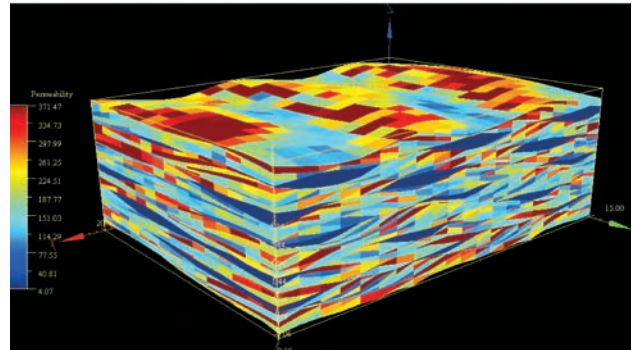
Users can generate effective property distributions for a single fluid phase by applying Single-Phase Upscaling to a digital model that accurately reflects rock properties such as sedimentary bedding structure and sand/shale ratios. The output can be used to populate large-scale grids for more accurate reservoir simulations.

- Calculate directional-dependent permeabilities for facies with different bedding geometries and sand/shale ratios.
- Calculate average porosity and net-to-gross ratio.
- Calculate flow-based permeability with periodic, linear and fixed boundary conditions.

A. Geological model of flaser bedding



B. Upscaled model of permeability distribution



C. Single-phase upscaling results

	Regular Grids			Irregular Grids		
Flow Simulation (Periodic Boundary Condition)						
Effective Permeability $K_{xx}$ $K_{yy}$ $K_{zz}$	131.9207	-0.6011	-4.3977	157.9426	0.1469	-2.3594
Effective Permeability $K_{yx}$ $K_{xy}$ $K_{yz}$	-1.0576	144.4025	-1.3931	0.0751	176.6054	-0.1572
Effective Permeability $K_{zx}$ $K_{xz}$ $K_{zy}$	-4.9015	-1.4135	35.5551	-2.3842	-0.1494	13.2300
Flow Simulation (Linear Boundary Condition)						
Effective Permeability $K_{xx}$ $K_{yy}$ $K_{zz}$	127.0527	0.6353	4.0879	136.5120	1.9889	1.9901
Effective Permeability $K_{yx}$ $K_{xy}$ $K_{yz}$	-2.5580	142.0164	1.1333	-3.0648	154.4743	10.0479
Effective Permeability $K_{zx}$ $K_{xz}$ $K_{zy}$	-6.3723	-0.6558	47.6939	-1.8188	-1.0602	22.1809
Flow Simulation (Fixed Boundary Condition)						
Effective Permeability $K_x$ , $K_y$ , $K_z$	128.1314	145.5128	36.6664	155.7092	179.7162	18.3202
Harmonic Average Permeability $K_x$ , $K_y$ , $K_z$	160.6116	160.6602	157.0285	182.5567	183.3177	71.1192
Average Porosity (fraction)	0.219			0.226		
Arithmetic Average Permeability	161.0333			183.4248		
Net-to-Gross Ratio (fraction)	0.874667			0.896743		

D. Multi-phase upscaling results

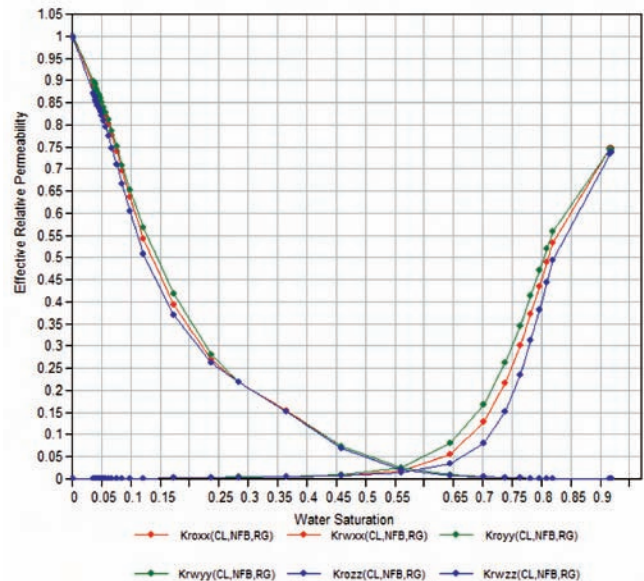


Figure 3. SBED modeling and upscaling method highlights important characteristics of the permeability distribution. (A) SBED digital models accurately reflect the bedding geometries and lithologies associated with sedimentary processes. (B) Permeability and porosity realizations are conditioned to these attributes in the upscaling process. (C) Single-phase upscaling of porosity and permeability grids. Note the relatively poor vertical permeability estimate ( $k_{zz} = 13$  md) resulting from the periodic boundary flow simulation in comparison to the simple harmonic average using irregular grid (71 md), simple harmonic average using regular grid (157 md) and simple arithmetic average using regular grid (161 md). (D) Two-phase upscaling of relative permeability curves. The resulting petrophysical simulations can be exported to the simulator independently or in combination with multiple flow units in a stacked SBED model. See Next Page

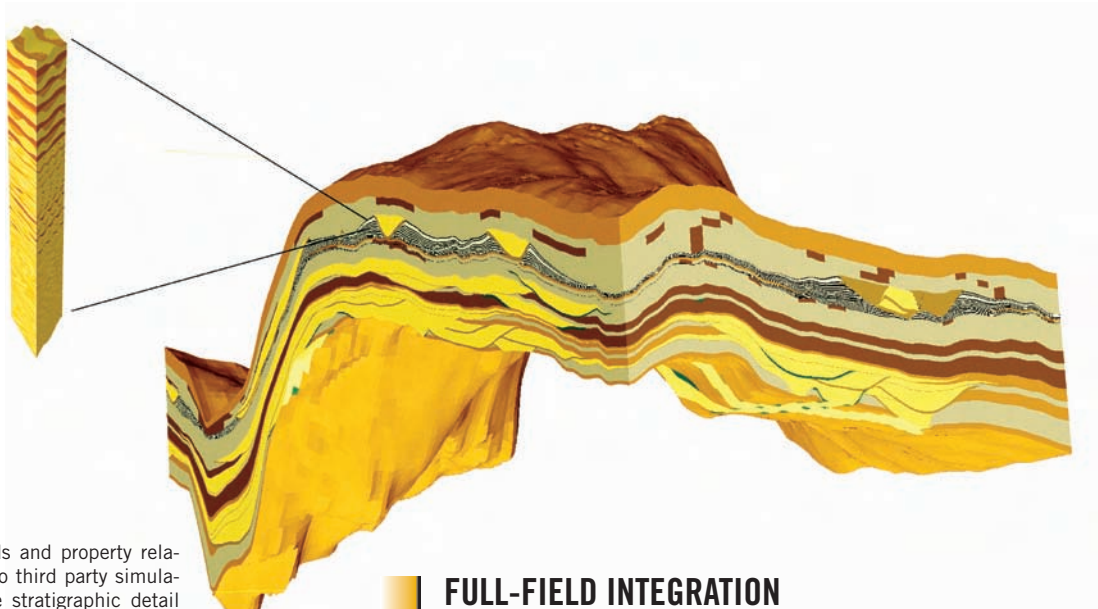
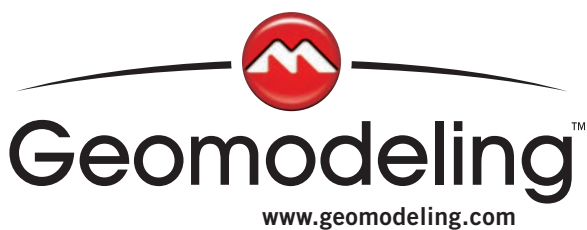


Figure 4. SBED grids and property relationships are input to third party simulators to provide more stratigraphic detail for accurate production estimates and recovery factors.

## FULL-FIELD INTEGRATION

SBED generates upscaled, facies-dependent property relationships for input to full-field reservoir simulators such as ECLIPSE or 3DSL (accessible as a plug-in within Geomodeling's SBEDStudio application).

- Export SBED geometry and property grids in ECLIPSE format.
- Display the relationship between facies associations and relative permeability and porosity.
- Assign upscaled property values to full-field reservoir grids with similar facies associations.
- Run simulations with SBED results to evaluate fluid distribution, sweep efficiency, recovery factors and geologic risk.



SBED is revolutionary software for small-scale (centimeter- to meter-scale) geological heterogeneity modeling and upscaling. The software provides detailed 3D geological models for input to reservoir simulators and generates petrophysical models that honor sedimentary processes. As a plug-in to reservoir interpretation workflows, SBED enables asset teams to identify thin bed potential, understand its impact on recoverable reserves, and choose optimal depletion strategies.