Fluvial Point Bar Modeling with MPS - Modern Analog Training Images and Application to the Kearl Oil Sands Mine, Alberta, CA

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Summary

This paper discusses two approaches to modeling fluvial point bars using Multi-Point Statistics (MPS). One method uses MPS for facies modeling with a function-based Training Image (TI) extracted from and applied to a point bar of the modern Brazos River, Texas, USA. The other uses a hybrid MPS/TGSIM approach to model facies of the McMurray Fm. as exposed in the Kearl Oil Sands mine, Lower Cretaceous, Northern Alberta. The mine model was based on “sketched” TIs extracted from two channel belts from the lower Mississippi Valley, USA.

Introduction

Reservoirs composed of point bar deposits are challenging to model because of difficult-to-predict lateral and vertical heterogeneities occurring over a wide range of length scales. The high probability of variations in rock properties at scales smaller than well spacing and below seismic resolution create significant uncertainties when attempting to build accurate reservoir facies models. MPS modeling algorithms can create realistic, complex facies geometries while honoring seismic and well conditioning, however, one or more appropriate TIs are required. Geologists typically use combinations of conceptual models, Lidar, satellite photos, wireline data, subsurface geophysical images, function-based modelling, outcrop data and/or other analog information to create these idealized, three dimensional characterizations.

There are a very limited number of existing, detailed spatial descriptions of ancient point bars facies, most derived from relatively small-scale systems (e.g., Hartley et al. 2015; Bhattacharyya et al. 2015). Descriptions of stratal geometries are a common theme in many modern and ancient point bar studies (e.g. Durkin et al. 2015). Training images derived from well-characterized modern or ancient depositional systems serve as a bridge between stratigraphic concepts and facies prediction within MPS geologic models. Constructing an appropriate training image is a major challenge when many of the key facies distributions are poorly understood.

We tested two end-member methods for building training images. The first, derived from the Modern Brazos River system, uses a mathematical function to describe the relationships among a suite of fluvial facies to simulate an application where the modeler has good facies and geometric control. The other method employs a representative map view surface “sketch” TI that captures the internal scroll geometries within large-scale point bars to test a scenario where 3D geometric control is lacking but there are abundant well penetrations as is the case in oil sands mines.

Function Based Training Image

For the active Brazos point-bar, a wide range of input data were available to construct the internal architecture, including historical maps and aerial photos, Electrical Resistivity Tomography, Ground
Penetrating Radar, core, cuttings, and wireline log data. To populate the basic facies trends in the TI, mathematical functions were used to describe a fining upward character, an upstream to downstream fining component, and vertical cyclicity with the thickest beds at the base and thinner beds at the top of the fluvial interval. The point bar TI was constructed in a horizontally-layered “sugar cube” framework where each horizontal TI layer represents a single time slice that is actually inclined in the subsurface. Cores and laser particle size analyses were used to define majority facies codes at different positions within the deposit from upstream to downstream, and from bar top to base. To capture the trends observed in the system, these majority facies codes were used as targets for optimizing a multivariate linear equation using the cell indices I, J, and K as independent variables. Then, these equations were used to assign facies code trends across all grid cells of the TI. Based on stratigraphic interpretation, four fining upward cycles were designed into the equation-based TI using look-up functions with the vertical cell index K as the independent variable. This idealized piece-wise linear function was designed to describe the locations and magnitudes of discontinuities (facies missing from the “normal succession”) across the boundaries of each depositional cycle. The areal and vertical cycle trend functions were combined to capture the idealized lateral and vertical trends and cycle bounding discontinuities in the TI. To add geologically realistic variations to the TI, Sequential Gaussian Simulation was used to make correlated Gaussian noise functions. The amplitude of the noise function was modified so that the highest scatter occurred at the base of each vertical cycle, decaying to zero amplitude at the top. A final, rank-preserving transform step was used to impose the correct facies proportions as interpreted from core and wireline log data. Finally, in an effort to adapt the analogue to the subsurface cases of interest, a conglomerate sub facies was created within the coarsest sand facies using a second correlated Gaussian noise function. (Fig. 1)

The function-based TI generated from the above steps was used in the MPS process for facies modeling in a 3D inclined layered geomodel. Modelling experiments demonstrated that MPS processes using this TI are able to replicate realistic stratigraphic trends and cyclicity. Although the TI and the MPS workflow produced a superior model for the Brazos point bar, the overall workflow with numerous facies was deemed too time-consuming and difficult to use in an operational setting. There was a need to simplify the
MPS workflow in a manner that would preserve its important advantages while reducing complexity and execution times.

**2D Modern Analogy Training Image**

Cores and wire line logs are the dominant data sources for the McMurray Fm fluvial model employed at the Kearl oil sands mine. Lacking seismic data or other subsurface geophysical imaging, the internal architecture is difficult to discern. An inclined layered framework was constructed by using core analyses, dip meter data, and other wireline logs. A hybrid MPS/Truncated Gaussian Simulation (TGSIM) facies model was built to control internal architectural elements and surfaces. The MPS algorithm was used to create a binary facies model capturing the architectures of the high-net and low-net point bar intervals. TGSIM was then employed in a final modeling step for generating facies distributions within the sand-prone units. The most critical step in the workflow was to ensure the TI accurately captures the scale and complexity of the key features of interest. In this example, two TIs were required to capture the complexity of stacked fluvial systems of different scales found within the McMurray Fm. Several factors that were considered in choosing appropriate TIs for the model including: channel width, depth, sinuosity, and orientation, positions of internal bar Re-Orientation Surfaces (ROS), distribution of chute channels and muddy inter-bed abundances.

Training Images were based on hand-drawn interpretations of satellite images of surficial depositional geometries observed in the lower Mississippi River valley. Images were developed for both large-scale and small-scale systems that comprise the upper (thicker, 35-45m) and lower (thinner, 15-25m) parts of Middle McMurray respectively (Fig. 2). Low-net facies were painted along each ROS incorporating a trend of increasing thickness and continuity along the internal bar surfaces in a downstream direction. Vector sketches were then scaled appropriately to decrease downwards to reflect fining-up trends seen in most point bars. Extruded deformations were applied to construct the 3D solid. The TI was then rotated to match the interpreted orientation of the actual point bars at Kearl. The facies proportions of the TI for each unit (model zone) was calibrated to the core-hole data or the expected proportions for the environment of deposition.

![Fig 2. Final training images for Large scale (left) and small scale (right) point-bar Model](image-url)
The TIs generated from the above steps were used in an MPS workflow for High-net/Low-Net facies groups (sub-EODs) represented in the inclined 3D layered geomodel framework. For each EOD, facies were modeled by TGSIM with a different variogram, Locally Varying Anisotropy (LVA, guided by dip data reconstruction for each zone) and probability trend. Modelling experiments show that this approach removes artificially hard edges to EOD boundaries and produces a smoother, more realistic geologic model without the clumps of facies that are commonly observed when using TGSIM alone. Observations of Kearl mine faces indicate that MPS predicts facies distributions more accurately than the TGSIM method, although more field observations are needed to validate this claim. A data decimation test was performed to investigate the impact of core hole spacing on the hybrid MPS/TGSIM model. Two scenarios were tested: 1) Reducing well density from a spacing of around 125 m to about 250 m. 2) Further reducing well density from 250 m to around 400 m. With reduced core control, the decimated MPS model does not show significant changes in the overall pattern of facies distributions compared to the original un-decimated MPS model. The TI effectively guides the model in areas of lower core-hole density and avoids the somewhat randomized interpolation of facies that occurs in the TGSIM process.

Conclusions

Oil Sands mines offer a unique opportunity to test a range of fluvial reservoir modelling approaches that can be validated by field observations from both cores and serially exposed mine faces. Lesson learned from the mine can be applied not only to nearby in-situ McMurray assets but also to conventional reservoirs in the deep subsurface that were also deposited by large-scale, sinuous fluvial systems.

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Reference