

Simulation of Petrophysical Property Trends within Facies Geobodies Modeled Using Multiple-Point Statistics

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Abstract Multiple-Point Statistics (MPS) simulation has emerged recently as a practical facies modeling technique to simulate complex geological patterns, such as sinuous channels, that cannot be modeled using variogram-based (two-point statistics) techniques. MPS simulation consists of extracting patterns from training images that describe the type of facies heterogeneity expected in the subsurface, and then reproducing similar patterns while honoring all conditioning data collected from the field under study. The next step in conventional reservoir modeling workflows consists of populating porosity, permeability and water saturation within the facies categories simulated by MPS. This step is typically performed using traditional variogram-based techniques such as Sequential Gaussian Simulation (SGS). However, in contrast to object-based modeling where intra-geobody coordinates can be computed while geobody objects are simulated, pixel-based methods such as MPS do not record the position of the cells relative to the simulated facies geobody; furthermore, there is no specification of geobodies in the facies model. Thus pixel-based facies models cannot directly provide SGS with the required information for reproducing petrophysical trends within individual facies geobodies, for example decreasing porosity from base to top, or from axis to margin in turbidite channels. Yet intra-geobody petrophysical property trends are commonly observed, particularly in clastic environments; they create preferential flow paths that may have a significant impact on reservoir performance.

In this paper, we propose two alternative workflows to simulate petrophysical property trends within facies geobodies modeled using MPS. The first solution requires generating a training image of the petrophysical property to be modeled within a particular facies, and then the original MPS simulation program SNESIM is modified to be able to simulate continuous variables by discretizing the range of (continuous) petrophysical property values into a limited number of categories.

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The second solution consists of post processing the MPS facies model to calculate the distance from each cell to the closest boundary of the geobody to which the cell belongs, either in 3D or along a particular plane or direction. Then a function of that distance, which can account for facies geobody overlap, is used as a local trend in SGS with locally varying mean.

Introduction

In most geological settings, petrophysical property spatial distribution (porosity, permeability, water saturation) is primarily controlled by depositional facies elements. Therefore a typical workflow to characterize conventional hydrocarbon reservoirs consists in first, generating a facies model based on the well data and geological interpretation, and then populating petrophysical properties within each facies using traditional variogram-based techniques such as SGS or cloud-transform. However this approach is challenged when intra-geobodies trends are expected to be present and may generate preferential flow paths that need to be integrated in the models (e.g. channel axes). Object-based modeling techniques can easily address this problem, but they have well-known limitations in terms of hard and soft data conditioning.

In this paper, two methods are proposed to model specific petrophysical continuity features within pixel-based facies models. The first method consists in reproducing petrophysical heterogeneity patterns using the modified SNESIM algorithm described in [5]. The second method, initially proposed in [3], aims at computing a distance function to geobody boundaries and using that distance as secondary information in SGS.

First approach using continuous MPS

Modeling continuous petrophysical property continuity patterns introduces the challenge of generating training images for continuous variables. Generating a continuous training image can actually be performed quite easily while generating the training image for the facies model. The technique is inspired from object-based modeling techniques: transverse (2D), longitudinal (2D) and vertical (1D) coordinates are calculated inside the geobodies generated in the training image (Figure 1).

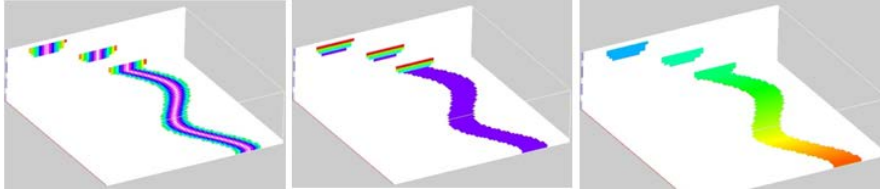


Figure 1: transverse (left), vertical (middle) and longitudinal (right) coordinates

The coordinate properties are then weighed and combined into a single property trend training image. Potential coordinate systems and combination schemes have been demonstrated previously [3, 4]. A stochastic component, typically an unconditional SGS simulated realization, could be added. The resulting continuous training image can be eventually transformed to match a target property histogram (Figure 2).

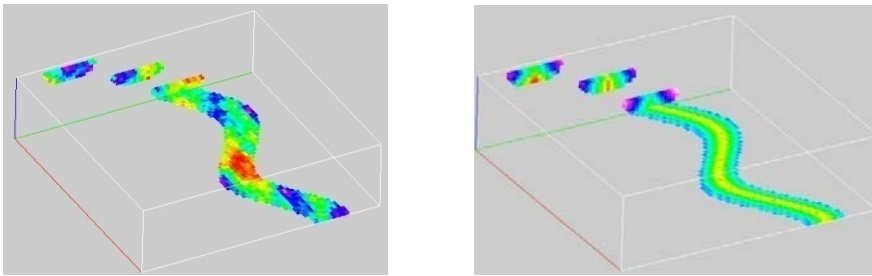


Figure 2: stochastic component for training image generation (left) and continuous training image

The next step consists in extracting patterns from that continuous training image. The original multi-point statistics simulation algorithm SNESIM only reproduces patterns of categorical property. Therefore the idea is to discretize the range of property values in the continuous training image into a small number of bins, and to consider these bins as categories to be simulated with SNESIM. The greater the number of categorical bins, the better petrophysical trends can be captured. However, reproducing complex patterns made of a large number of facies or categories can be challenging for SNESIM. As a rule of thumb, using 4 to 6 categories is a good compromise.

This technique is applied to two different cases (Figure 3):

- A channelized system environment where porosity is expected to be high along channel axis and decreasing towards channel margins.
- A tidal environment with sand bars where porosity is expected to be high at the center of the bars and to decrease toward the edges.

Using this first approach, since intra-geobodies coordinates are computed as depositional elements are generated, geobody overlap (e.g. eroding channels) is

accounted for in the continuous training image and reproduced reasonably well in the resulting petrophysical property model.

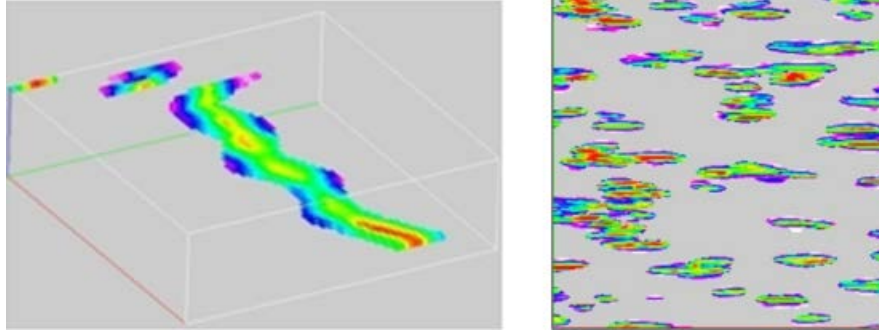


Figure 3: Continuous MPS realizations - Channel (left) and Sand Bars (right)

Second approach using distance-based intra-geobody trends

Object-based modeling techniques can easily compute intra-geobody coordinates as objects are generated, in contrast to pixel-based methods, which are unable to record local information about individual geobodies. The second approach proposed in this paper is to post-process pixel-based models in order to produce an equivalent form of depositional coordinates based on intra-geobody distances, and then to use these pseudo-depositional coordinates to constrain the simulation of petrophysical properties.

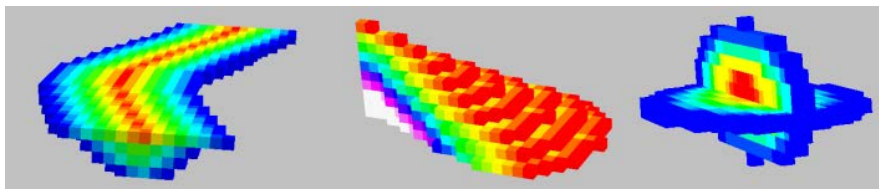


Figure 4: Distance function calculations on a channel in 2D (left), on a lobe in 1D (middle) and a spheroid in 3D (right)

The distance from each cell to the closest geobody boundary can be computed using the Chamfer Euclidian distance function [2], either in any direction (3D), or on any plane (2D), or along any line (1D). Highest distance values correspond to the central part of the facies objects whereas lowest distance values correspond to object edges. When applied to a channel object, channel axis can clearly be identified as corresponding to the highest distance value cells (Figure 4).

Calculating different types of distances (1D, 2D and 3D) in different directions (horizontal plane, vertical plane, etc...) allows accounting for various types of depositional trends. For instance, a trend based on a simple 1D distance measure allows characterizing sand deposition in crevasse lobes, whereas in spheroid type facies elements, a full 3D distance computed from the center of each element may be required (Figure 4).

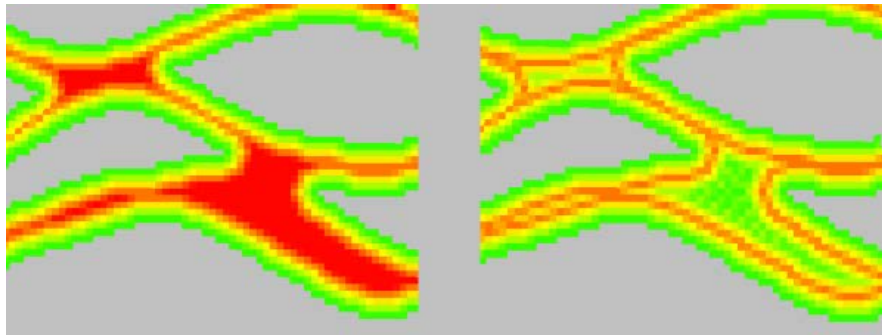


Figure 5: Distance function on amalgamated channels without removing overlap (left) and with removing overlap (right)

Although this second approach works reasonably well for individual geobodies, problems may appear when facies elements are amalgamated, such as when complex channels are stacked on top of each other or cross each other. To take geobody overlap into account, distance cycles can be introduced with a frequency corresponding to the average size of the geobodies. This solution helps to improve simulated results although some artifacts can still be present (Figure 5).

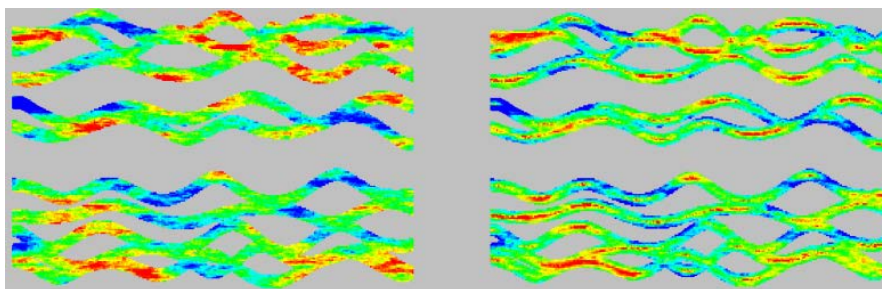


Figure 6: Porosity simulated using SGS (left) and SGS with locally varying mean (right)

Once these intra-geobodies trends are calculated from the facies model, they can be used to simulate petrophysical properties using SGS with locally varying mean. Figure 6 compares a porosity model simulated using traditional SGS versus a model that takes into account intra-geobodies trends. Results are more

geological when porosity trends follow the orientation of the channels. Flow simulation results are not presented in this paper, but preferential flow paths derived from porosity and permeability trends along channel axis are expected to have a significant impact on reservoir flow performance forecasting.

In some circumstances it may be important to capture within facies geobodies locally variable directions of spatial continuity in addition to locally variable means. In these cases, these workflows may be augmented with methods to extract locally variable azimuth fields from the MPS facies models as demonstrated by Boisvert and others (2011) [1].

Conclusion

Two methods to model petrophysical property trends within facies geobodies were presented. The first method requires the construction of a continuous training image and uses a modified version of the MPS simulation program SNESIM, while the second method estimated the trend directly from the facies model and accounts for that trend using SGS with locally varying mean.

Even though options proposed to account for geobodies overlap can be improved, initial results obtained from both methods are very promising in terms of intra-geobody trend reproduction. Future work includes the computation of geobody local orientations from facies models, to be used as a local azimuth field constraint in SGS when simulating petrophysical simulations.

The next step to validate our work is to run flow simulations and evaluate the impact of the preferential flow path potentially created.

Bibliography

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