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Frequentist Meets Spatialist: A Marriage Made in Reservoir Characterization and Modeling

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Abstract

As a branch of spatial statistics, geostatistics is commonly used to model geologic facies and petrophysical properties. The spatial characteristics of geostatistical methods in variogram, kriging and stochastic simulation have made them the tools of choice for reservoir modeling. Such techniques are especially useful to characterize the reservoir connectivity and sweep efficiency. However, geostatistical modeling methods do not always make an accurate inference of reservoir properties from well-logs to a reservoir model because of the stationarity and ergodicity assumptions and the multiscale of subsurface heterogeneities. This often causes incorrect frequency statistics of reservoir properties, which typically exhibit a non-Gaussian distribution. As a result, estimation of the hydrocarbon in-place and recoverable reserves can be grossly inaccurate and hundreds of millions of barrels of hydrocarbons can be lost or fictitiously added in a reservoir model. An accurate reservoir characterization should include not only the realistic description of the spatial continuity but also the sound inference of the reservoir properties from fine-scale well-logs to coarse-scale reservoir models. The latter can be achieved through appropriate inference of frequency statistics coupled with spatial statistics.

An application of using both spatial and frequency statistics in a real reservoir modeling example is presented. Facies probability maps were derived from geologic propensity analysis coupled with well-log data, and used for constraining the model to honor the facies spatial association of the reef complex. Careful examination of frequency statistics helped to detect the estimation biases in the initial geostatistical model. An enhanced reservoir modeling workflow with inference coupling spatial and frequency characteristics of the geologic propensity and well-log data was developed, which resulted in a more realistic model. The history match and production performance forecast using the new model was straightforward. More importantly, the new model shows more than 100 million barrels of additional oil in-place compared to the previous geostatistical models and uncertainty evaluation based on the facies scenarios and other geologic and petrophysical variables confirms the new result. The realization of more subsurface resource has implications for future field development to target unswept oils in the reservoir.

Introduction

Probability and statistical applications have seen significant progress in the last two centuries. Broadly speaking, Bayesian statistics was more commonly used in the nineteenth century, while frequency statistics played a more dominant role in the scientific applications in the twentieth century (Efron 2004). In geoscience and reservoir engineering, however, spatial statistics has seen more extensive applications in the last half century (Matheron 1962, 1965, Journel and Huijbregts 1978, Cressie 1991, Chiles and Delfiner 1999). Geostatistics, as a major branch of spatial statistics, is commonly used to model geologic facies and petrophysical properties in reservoir characterization. The spatial characteristics of geostatistical methods in variogram, kriging and stochastic simulation make them the tools of choice for reservoir modeling. Such techniques are especially useful to characterize geologic facies object size, petrophysical property continuity and reservoir connectivity (Journel and Alabert 1988, Jones and Ma 2001, Deutsch 2002).

While there are many advantages of geostatistical simulation methods compared to traditional interpolation-based techniques, various pitfalls and limitations exist in geostatistical applications in 3D reservoir modeling. For example, although variogram is a relatively good quantitative measure of geologic object size, it does not carry information about the spatial positions of the geologic objects (Ma 2008b), yet it is well known that the spatial positions of facies bodies and flow units significantly influence the subsurface fluid flows (Damsleth and Holden 1994). For continuous variables, such as petrophysical