

Facies Simulation in Practice: Lithotype proportion mapping and Plurigaussian Simulation, a powerful combination

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Abstract Geostatistical simulation of facies has become part of the mainstream workflow when building stochastic geocellular models. However, modelers are presented with a plethora of challenges when attempting to produce models based on real data, including honoring depositional facies boundary conditions and their proportions, honoring data in the presence of numerous or closely spaced wells, capturing post depositional overprinting, and accounting for non-stationarity. These challenges often require unavailable tools and even the lack of modeling skills. Although the technology has evolved during the past 60 years and many sophisticated techniques exist, only a few of the methods are available in commercial software. The most commonly used facies modeling algorithms tend to satisfy some but not all of these issues, but fall short on many more. Sequential Indicator simulation, the most popular method, lacks the ability to honor facies boundary conditions, Truncated Gaussian Simulation handles simple facies transitional boundaries, and while Object Simulation manages most non-overprinted complex facies sets, but it is unstable in the presence of numerous or closely spaced wells. Non-stationarity compounds the problem and a simple detrending of the data often results in an unsatisfactory solution. One powerful combination of methodologies is the use of a Lithotype Proportion Matrix with pixel-based facies simulation algorithms. There are a numerous advantages to this

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approach, not least of which is its simplicity and usability. The Lithotype Proportion Map consists of hundreds of high resolution trend maps (proportion curves) accounting for non-stationarity for each facies within every reservoir k-layer and interval. Furthermore, the individual proportion curves used in its construction can be edited to further capture subtle or explicit features based on a conceptual geological model. The Lithotype Proportion Map first implemented in Truncated Gaussian Simulation and then with its extension, Plurigaussian Simulation, when used with SIS substantially improves the results with respect to many of its known issues. While incorporating trends and conceptual geological models is possible in other ways by expert modelers, the challenge is to provide robust tools that allow practitioners at all skill levels to model successfully in a timely and intuitive fashion. The implementation of a Lithotype Proportion Map in combination with pixel-based methods like SIS, TGS, and PGS provides a workflow that is both powerful and easy to use.

Introduction

Most of the geostatistical-based interpolation and simulation formulations for facies modeling were well established by 1975, principally by George Matheron and his students. By 1985 many had been coded for research and by 1995 they became available commercially to the petroleum industry. Although geostatistical methods were applied initially in the mining industry, the first petroleum based applications occurred by the mid to late 1970's [1, 2]. Although the results looked promising, the methods did not reach wide-spread popularity until the late 1980's and early 1990's with the advent of more powerful desktop computing; ultimately replacing mainframe computer mapping. Between 1987 and 1992 a number of software companies provided spatial modeling techniques proposed earlier by Matheron which had evolved over the previous 30 years. HERESIM, IRAP, RMS, STORM, MOHERES, and RC2 are but a few of the of the products that emerged during this time, offering methods such as Truncated Gaussian Simulation (TGS), Sequential Indicator Simulation (SIS), and Object Modeling. Interestingly, little has changed in the last 20 years with respect to commercially available facies modeling methods; with two exceptions: 1) Plurigaussian Simulation (PGS), an extension of TGS, was first published in 1994 [3] but not introduced commercially until 1997, and 2) Multipoint Simulation (MPS) was first published in 2002 [4] and commercialized in 2010.

Overcoming Limitations

While spatial modeling methods for both indicator and continuous property modeling have now been used in the Petroleum industry for more than 35 years, our observations, particularly over the last 10 years, are that it has largely remained a tool used by experts. Informal surveys such as those performed at the recent Gussow conference in Canada [5] confirm these observations and suggest that most practitioners consider would prefer the software to be more user-friendly and intuitive. We also find that 50% of all practitioners, new and experienced, admit to not understanding the basic principles underlying the methods in the software products they use and most often do not have additional access to adequate resources for in-depth help or education. By default, most use SIS for facies modeling because it is perceived to be “easy” to use. Finally, 40% - 50% have less than 5 years of modeling experience and have built less than 6 models [5]. These statistics, while informal, point to an obvious conclusion; the need for better usability and parameterization transparency (intelligent defaults) of the methods that software packages deliver. Without question, improvements in these two areas will benefit not only the newer modelers, but also those with experience.

While SIS, TGS, and Object modeling methods are the most commonly used, they are not without their limitations and are not universally applicable to all depositional systems. Parameterization, including spatial models, trends, and the introduction of conceptual geological information can be complicated and unintuitive depending upon the specific limitations associated with each method. Poorly parameterized simulations intended to capture uncertainty can lead to very expensive mistakes. These limitations are well known [6, 7, 8] and in part stimulated the development of PGS and MPS, both of which attempt to overcome the various shortcomings.

Introducing Trends and Conceptual Geological Information

A major limitation of the simulation methods discussed occurs during the introduction of trends to handle non-stationarity. Commonly, for pixel-based methods, trend functions are introduced to manage this. Alternatively for vertical trends, a vertical proportion curve can be introduced [9]. Trends in Object models must be inferred from a variety of parameters by including intensity of the object process and local proportions [10]. In addition, secondary data such as seismic attributes can be introduced using co-simulation to capture trends in either pixel or object models.

Incorporating conceptual geological information in the model can be even more difficult. Defining the appropriate stratigraphic layering can help control some of the stratigraphic geometries and the introduction of secondary information such as seismic data may help introduce larger scale features

including trends. Two-dimensional deterministic maps can be used as co-variables or in the case of MPS, 2D and 3D training images must also be used. In the latter case, our observation is that the process has shown some promise, but it is cumbersome, requiring a level of expertise not common among most users. We propose the use of a vertical proportion matrix, referred to here as a Lithotype Proportion Matrix (LPM). The LPM allows modelers to control both trends and conceptual information more precisely and simply than current practices. While this method is not new [11], it has principally been applied to TGS and PGS methods. Here, we not only show the strength of the LPM and simplicity of use for these algorithms, we also show its extension to SIS and demonstrate improved results.

West Texas Field Data

The west Texas field (WTF) is located on the eastern edge of the Central Basin platform in the west Texas Permian basin. In the study area (Figure 1), production is from the Guadalupian Grayburg Formation (Permian), which is transitional between the previously more open marine conditions of the San Andres Formation and the more arid sabkha and siliciclastic eolian dune field environment of the younger Queen Formation.

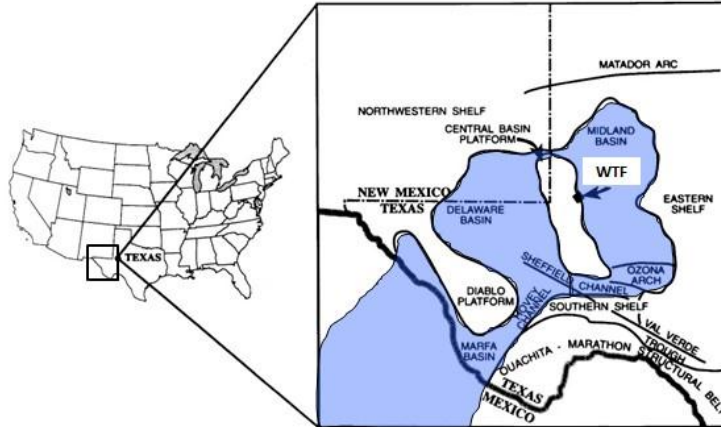


Figure 1. Location of the west Texas field.

Lithologically, the Grayburg is composed of alternating dolomite and siltstone for a total thickness of about 140 meters. Dolomites range from anhydritic skeletal wackestones through mudstones. Porosity is moldic or vuggy and can be extensively plugged by anhydrite. The siltstones are dominantly angular to subrounded quartz grains with angular feldspathic grains, which commonly alter

to clay, often plugging pore throats. Siltstone porosity is intergranular. This formation has a characteristic shoaling-upward, prograding sedimentary motif, ranging from shallow open-marine to tidal flat/sabkha sediments. The silt is believed to be of eolian origin, reworked by strandline processes into a series of thin, offlapping shoals. Progradation of the carbonate shelf was approximately from west to east. Structurally, the reservoir is a north-south-trending asymmetrical anticline, dipping gently eastward into the Midland basin. The Permian climatic regime was similar to the Plio-Pleistocene with major periods of glaciation. The carbonates formed during interglacial periods of relative high sea-level, whereas the eolian siltstones were most likely deposited during low sea level glacial periods with a source from the present day SE New Mexico.

Lithotype Proportion Matrix

The LPM consists of lithology curves representing the facies proportions lithotypes (grouped facies) locally for every blocked layer throughout the model. For the stationarity case (Figure 2A), a single proportion curve is calculated from the pooled set of well control. In non-stationary cases, local proportion curves are created from grouped wells (Figure 2B) located near one another that share similar facies relationships. These are referred to as grouped proportion curves. The LPM (Figure 2C) is computed by interpolating the grouped proportion curves to the geocellular grid. The result is essentially a suite of hundreds of trend maps; one for each lithotype, in each layer, throughout all layers and all intervals.

The purpose of the LPM is to introduce secondary information, minimally, the various trends in the data. For example, Figure 2C shows the evaporite facies (pink) increasing in proportion to the east (right) and the siltstone facies (yellow) increasing to the north (up). If a practitioner chooses to modify these trends or insert a geometric pattern of facies related to the conceptual geologic model, the grouped proportion curves may be edited and copied to desired locations as “pseudo” proportion curves. Thus, when the LPM is recreated, this updated secondary information is captured and ready to be used in subsequent simulations. Figure 3 illustrates a modified LPM which captures a high permeability feature by modifying the proportions to include better quality reservoir (red) in a channel-like feature.

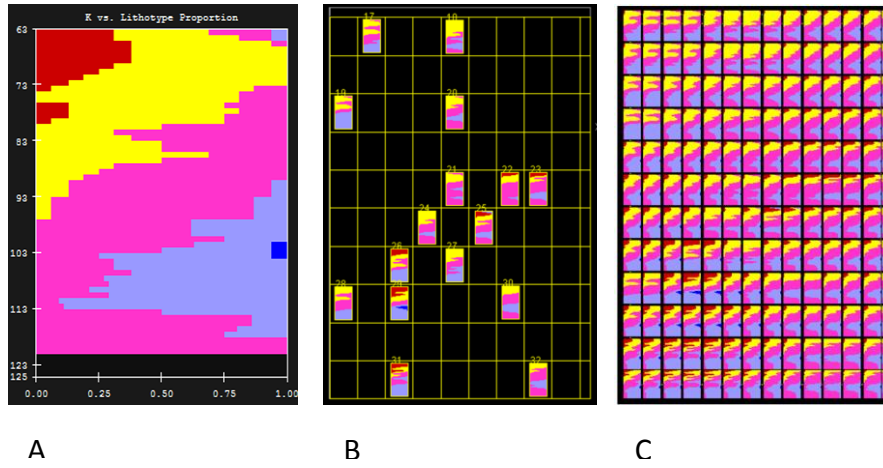


Figure 2: Interval 2 Proportion curves and matrix. A. Vertical Proportion Curve, stationary case; B. Grouped Proportion Curves; C. Lithotype Proportion Matrix, non-stationary case

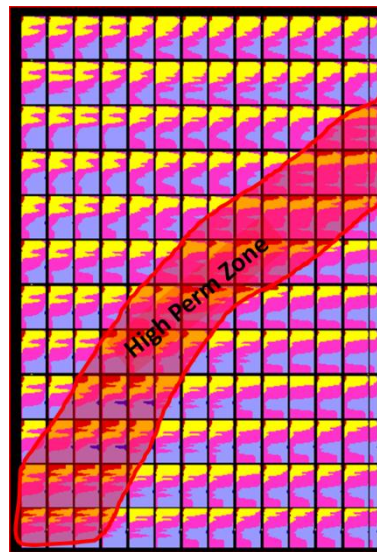


Figure 3: LMP showing a user defined region of better quality reservoir relating to high permeability

Results

Two different LPMs were created; one allowing the grouped proportion curves to be interpolated with no modification or introduction of pseudo proportion curves, and one with modifications to introduce a continuous geometric zone of better reservoir quality (siltstone – thief zone) known to be present. Each of these was used with three different modeling methods; SIS, TGS, and PGS respectively. For SIS, a simulation is shown with no introduction of secondary information at all in order to demonstrate the general effect LPM has on this particular method. The results are shown below.

Sequential Indicator Simulation

Figure 4A illustrates typical results when using SIS without a secondary constraint, such as an LPM. The results are noisy, there is no control over facies boundary conditions (note dolomites against siltstone in lower right), and facies occur in areas where they do not belong (note cross-section lower left thief-zone siltstone (red) should not be in contact with the evaporites (pink) and is present only near the top of the interval). Immediate improvement is seen, with the introduction of the LPM (Figure 4B). The dolomite is now absent in lower right and the thief-zone siltstone does not occur in lower left of cross-section. Only modest improvement is seen when using the edited LPM (Figure 4C). While generally improved with the introduction of the LPM, the zone of high permeability does not show the degree of continuity based on our conceptual model. It is still expressed at this interval as two separated bodies.

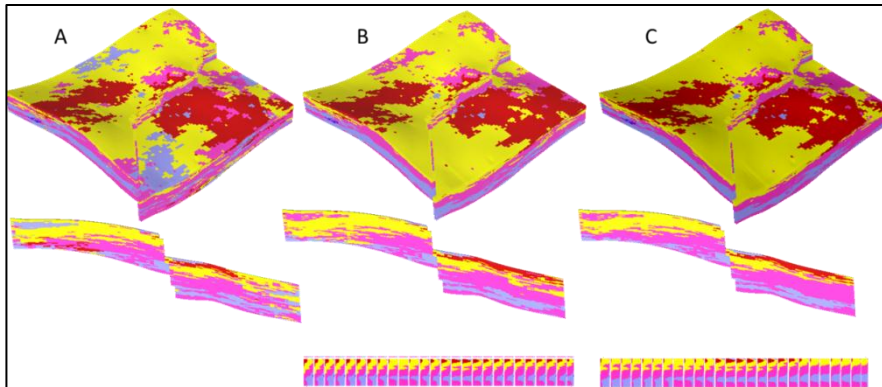


Figure 4: SIS results with no LPM (A), the raw LPM (B), and the edited LPM (C). The proportion curves are shown for the cross-sectional view.

Truncated Gaussian Simulation

Because the TGS method assumes a logical ordering or transition between the lithologies and the controlled by the LPM, the data and variogram, the results also show same ordering in the lithologies. The highly permeable facies (red) is restricted to the top of the interval, as it should be, and all the facies thin and thicken demonstrating various degrees of non-stationarity. However, the raw LPM (5A) does not completely capture the expected continuity of the thief-zone siltstone, based on our conceptual model, due to the relative sparse well control (Figure 6). Figure 5B shows the impact of the edited LPM by showing improved connectivity and more tightly controlled pattern resulting in a much better match to the conceptual model.

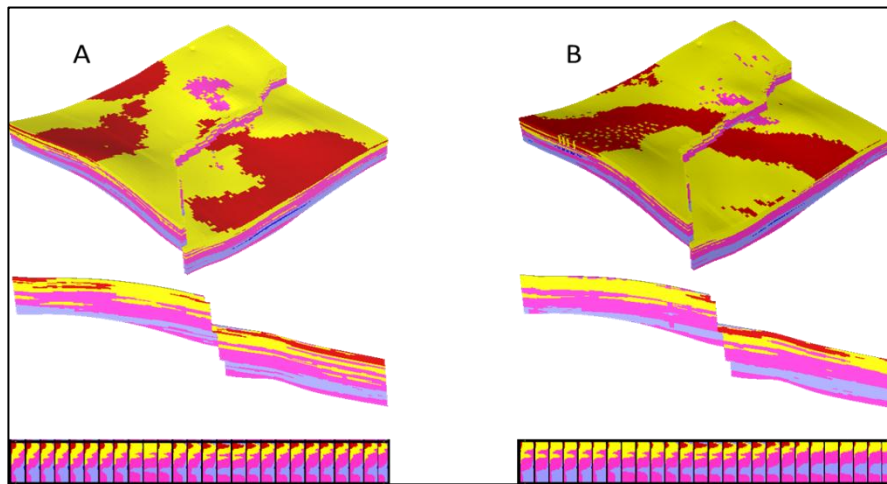


Figure 5: TGS results with the raw LPM (A) and the edited LPM (B). The proportion curves are shown for the cross-sectional view.

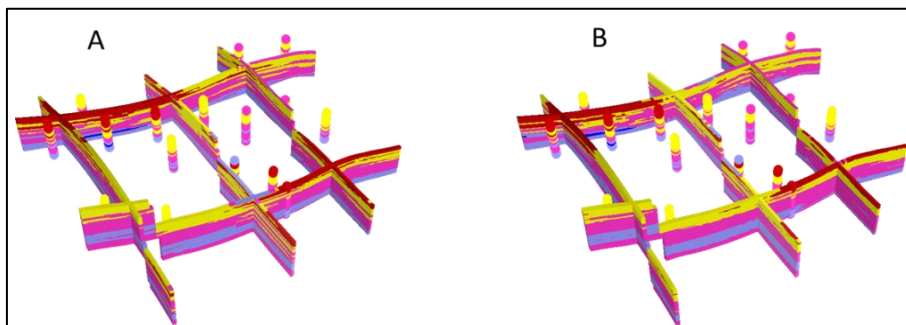


Figure 6: TGS fence diagram showing the well control with the raw LPM (A) and the edited LPM (B).

Plurigaussian Gaussian Simulation

Like TGS, PGS assumes lithology transitions but unlike TGS it can use two variograms; one for each of the two lithology sets. In this example, lithology set one variogram controls the two siltstone lithologies and the two dolomite lithologies, whereas the second variogram primarily controls the geometry of the evaporite facies (pink). Figure 7A shows poorer connectivity of the highly permeable facies due to sparse well control, but does show better distribution of the evaporites (pink) which have a different spatial model than the other lithotypes. Here again, non-stationarity is properly depicted. 7B shows improved connectivity of the better reservoir facies and a tighter distribution as expected due to the modification of the LPM.

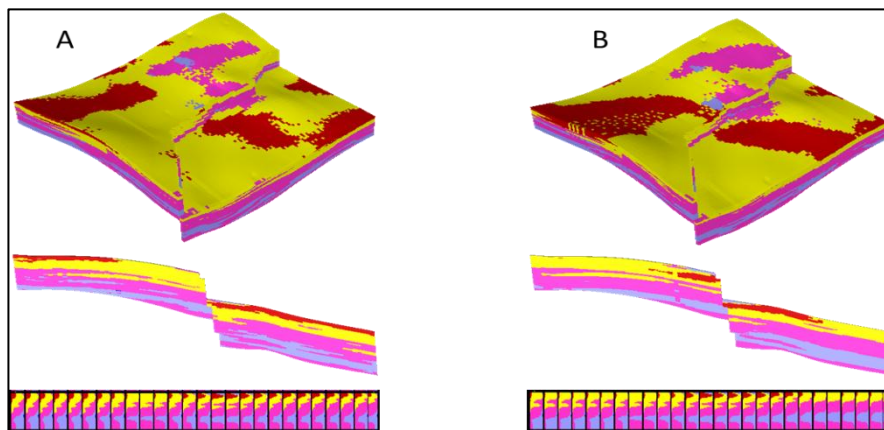


Figure 7: PGS results with the raw LPM (A) and the edited LPM (B). The proportion curves are shown for the cross-sectional view.

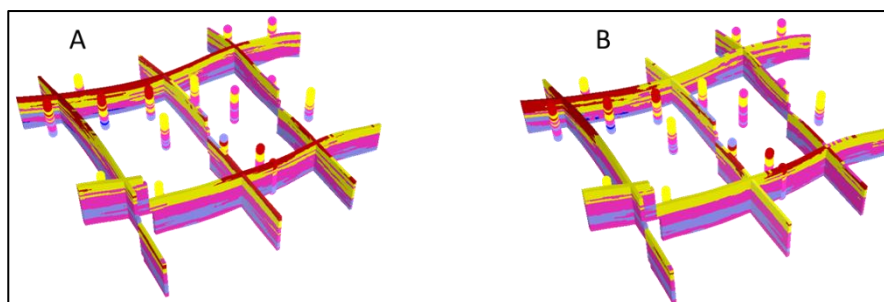


Figure 8: PGS fence diagram showing the well control with the raw LPM (A) and the edited LPM (B).

Conclusions

Modelers are faced with a variety of challenges when building geocellular models. One significant challenge centers on facies modeling. Practitioners are driven by the depositional models they understand, but all too often the mathematical methods they use are less understood. The selection of a simulation algorithm and the methods used to introduce trends and conceptual geologic information are two potentially significant areas where problems may arise. To address these issues, we propose that common facies simulation algorithms be combined with the use of a Lithotype Proportion Matrix. While other solutions exist to capture trends and conceptual information, the LPM offers an appealing solution to modelers with a wide range of skill sets and experience. Further, while LPMs are not new, and have traditionally been applied to both TGS and PLG, we demonstrate an extension of its use to include SIS. This particular combination is compelling not only because it facilitates the introduction of secondary information in a popular facies simulation method, but also has the effect of correcting many known algorithmic issues.

References

1. Haas, A.G., & Viallix, J.R.: Kriging applied to geophysics. *Geophysical Prospecting*, Vol. 24, pp. 49–69 (1976)
2. Delhomme, A.E. K., and Giannesini, J. R.: New reservoir description techniques improve simulation results in Hassi-Moussaud field, Algeria. *Society of Petroleum Engineers Paper No. 8435*, 11pp. (1979)
3. Le Loc'h G., Beucher H., Galli A., Doligez B., and Heresim Group: Improvement in the truncated Gaussian method: combining several Gaussian functions. *In Proc. ECMOR IV, Fourth European Conference on the Mathematics of Oil Recovery*, June 7-10, Roros, Norway. 13 p. (1994)
4. Guardiano, F. and Srivastava, R. M.: Multivariate geostatistics: beyond bivariate moments. *In, Geostat Troia 1992*, ed. Soares, Kluwer publisher, London, UK (1992)
5. Gussow Geoscience Conference, (Sept - Oct): *Advances in Applied Geomodeling for Hydrocarbon Reservoirs - Closing the Gap*, unpublished survey (2011)
6. Emery, X.: 2004 Properties and Limitations of Sequential Indicator *Simulation*. *In Stochastic Environmental Research and Risk Assessment*. Vol. 18 no. 6, pp. 414-424. (2004)
7. Mariethoz G., Renard P., Cornaton F., Jaquet O.: Truncated plurigaussian simulations to characterize aquifer heterogeneity. *In Ground Water* Vol. 47 No. 1, pp. 13-24. (2009)
8. Lantuéjoul, C. *Geostatistical Simulation*, Springer-Verlag, Berlin, Heidelberg, Germany, 256p. (2002)
9. Deutsch, C. V.: *Geostatistical Reservoir Modeling*, Oxford University Press New York, N.Y. (2002)
10. Allard, D., Froidevaux, R., Biver, P.: Accounting for non-stationarity and interactions in object simulation for reservoir heterogeneity characterization, *In Geostatistics Banff, 2004*, Eds. O. Leuangthong and C. V. Deutsch, Vol.1, p. 165-164. (2004)
11. Armstrong M., Galli A., Le Loc'h G., Geffroy F., Eschard R.: *Plurigaussian Simulations in Geosciences*, Springer Verlag, Berlin. (2003)