PGE 383 - Stochastic Methods for Reservoir Modeling - Spring 2019

Project Update #5 by Team 8, Simulation
Name: Fernando A Apango, Gurtej S Saini, Tharit Tangkijwanichakul, Bochao Zhao

Executive Summary

The purpose of this update is to assess and present the subsurface uncertainty, facies proportion, porosity, and permeability in particular by using sequential gaussian simulation (SGSIM), sequential indicator simulation, and cosimulation.
The work included:

- Simulation of 20 realizations of facies
- Simulation of 20 realizations of porosity by facies
- Cosimulation of 20 realization of permeability using porosity, by facies
- Checking histograms and variograms of realizations
- Combined map of porosity and permeability using cookie-cutter approach

As compared to estimation by kriging, the main purpose of generating multiple realizations (by running multiple simulations) is to be able to do away with the effect of smoothing the data away from the range, i.e. be able to capture spatial variability. It can be observed that the various realizations for facies, porosity and permeability are able to reproduce the original histograms and the variograms, while honoring the local data values. The generated realizations for porosity and permeability are also seen to reproduce the original bivariate relationship with reasonable accuracy.

Description of Workflows and Methods

1. Calculation of the trend in the facies and the porosity data
2. Calculating the correlation coefficient between normal-score transformed porosity and permeability, for both the facies
3. Sequential indicator simulation of facies, accounting for the trend in the facies using simple kriging
4. Removal of the trend from the porosity data to generate the residual data
5. Using the porosity residual data, and the corresponding variogram, to run twenty SGSIMs, each with a different ransom seed, independently for both the facies, and adding the trend back in at the end of the simulation
6. Using the simulated realizations of the porosity by facies, and the permeability variograms (for the respective facies), conducting co-simulations to generate 20 permeability realizations
7. Evaluating the histograms and variograms of simulated data compared to primary data
8. Building combined maps for each porosity and permeability realization by using the cookie-cutter approach

Results and Discussion

- **Facies Simulation (20 realizations)**

The underlying trend in the facies data was first identified using a gaussian moving window, which was then removed to generate residual data. The residual data was subsequently used to run twenty random sequential indicator simulations using simple kriging based on the variograms identified in the previous updates, and three of the realizations are shown in Figure 1.

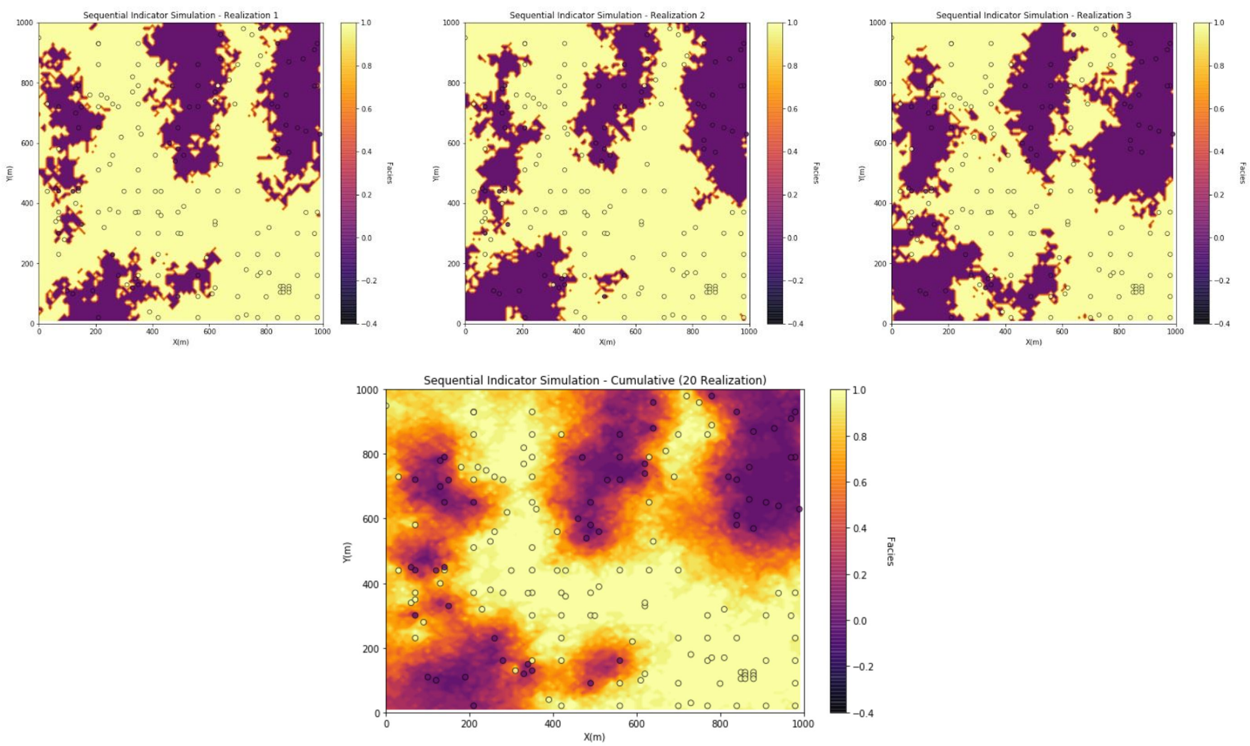

Figure 1. Examples of facies realizations (top) Equally weighted averaged facies realizations from 20 realizations (bottom)

- **Porosity Simulation by facies (20 realizations)**

  The porosity trend is first calculated using moving gaussian window. Subsequently, well porosity data is subtracted by calculated trend to get porosity residual. Then, sequential Gaussian simulation is performed, by facies, to obtain simulated porosity at unknown locations. Finally, trend is added back to residual porosity to obtain overall porosity map.
  It is clear that by using sequential Gaussian simulation, the spatial continuity and directionality are honored and noticeable in Figure 2.

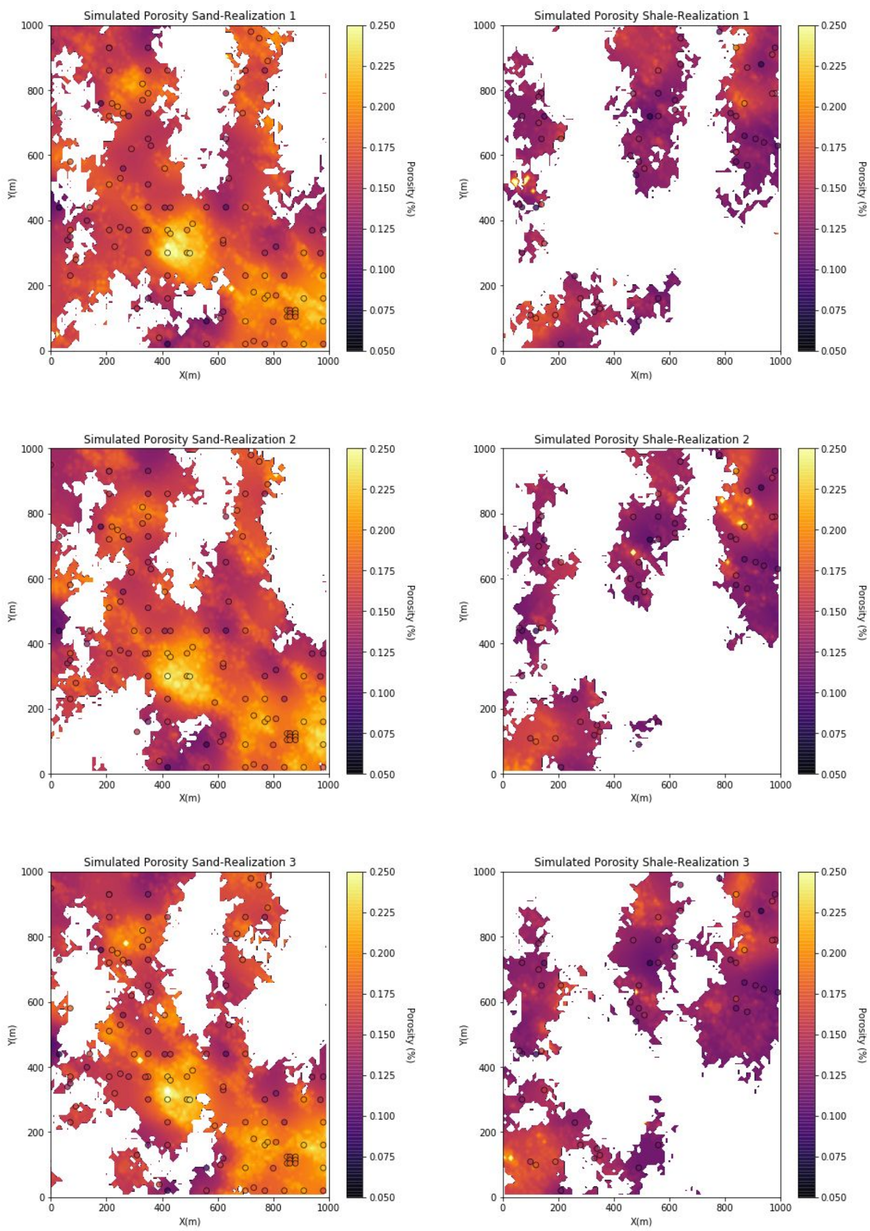

Figure 2. Examples of SGSIMs porosity realizations by facies

- **Permeability Cosimulation**

  To generate realizations for permeability over the area of interest, continuous cosimulations were run. The methodology used was collocated cokriging, with the markov assumption and bayesian updating simplifications. Therefore, these cosimulations required the use of correlation coefficient between porosity and permeability data, the previously generated porosity realizations and the variogram model for the permeability generated for the previous updates.

  Permeability was then cosimulated, by facies, using its corresponding porosity realization. Strong spatial continuity is honored and present in permeability map (in log scale for this study). Generally, sand facies will represent a higher permeability region while shale facies shows the opposite. Both facies show similar directionality.

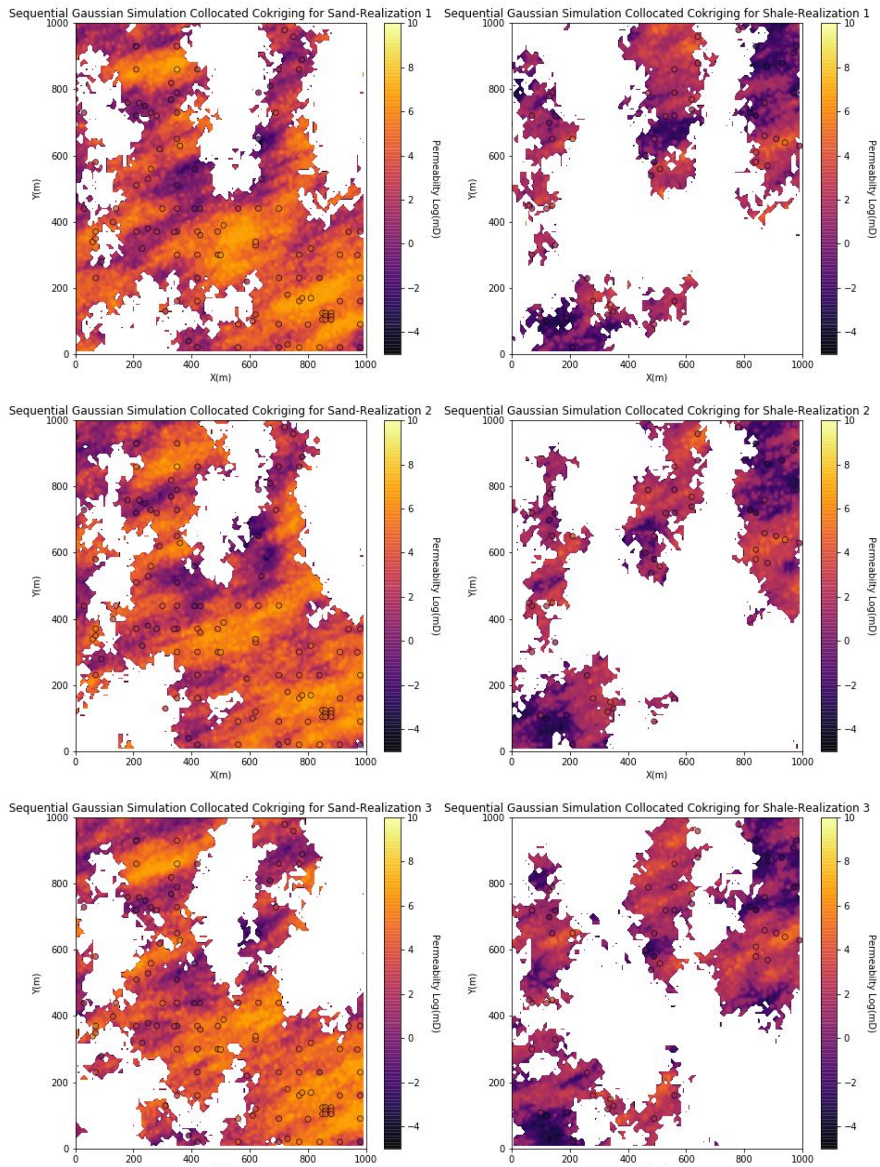

Figure 3. Examples of cosimulated permeability realizations by facies

- **Verification of input statistics (Histograms and variograms)**

For each of the realization of facies, porosity and permeability over the given area, histograms and variograms were generated. To generate the variograms, the angle in cell offset, closest to the major and minor axis was found, for each of the properties. The histograms and the variograms for the the data three realizations is shown in the following figures.

<u>Facies</u>

As it can be observed in Figure 4, the facies proportion histograms generated for the three simulations are similar to the histogram generated using the original data.

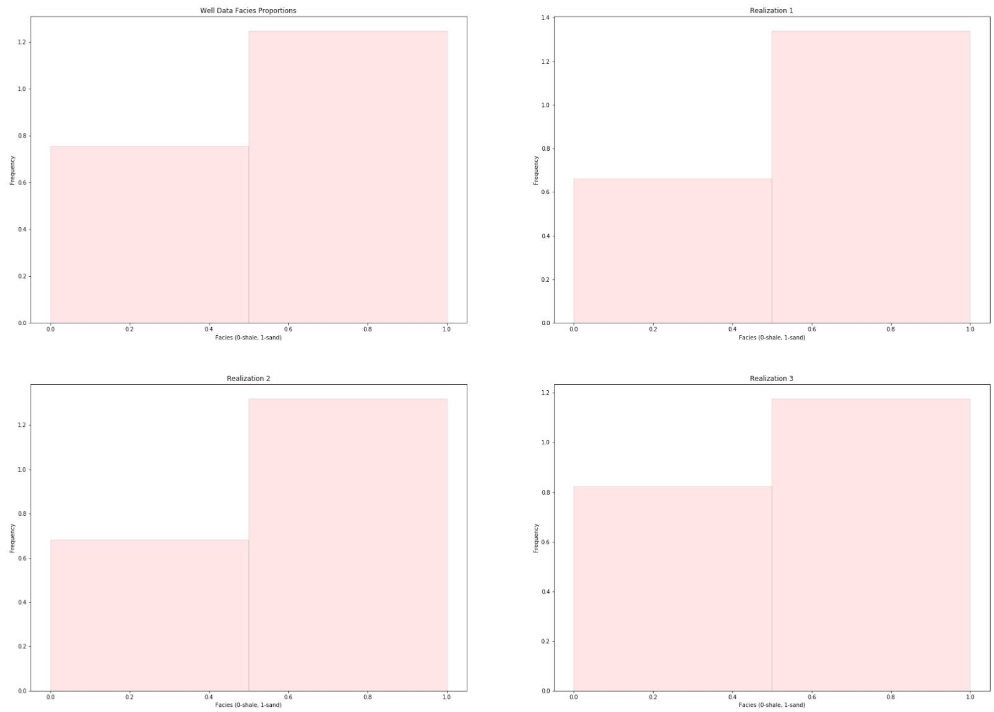

Figure 4. Facies proportion histograms for first three realizations compared with well data

Similarly, the variograms generated for three realizations of facies proportions match the experimental variogram and the variogram model generated using the original data.
The facies variogram's major and minor axes were 67.5 degrees and 157.5 degrees respectively, thus the corresponding x and y offsets were identified as 5 and -2 , and 2 and 5 respectively.
There are some ergodic fluctuations though, and they could be due to difference in the spatial continuity to the size of the model.

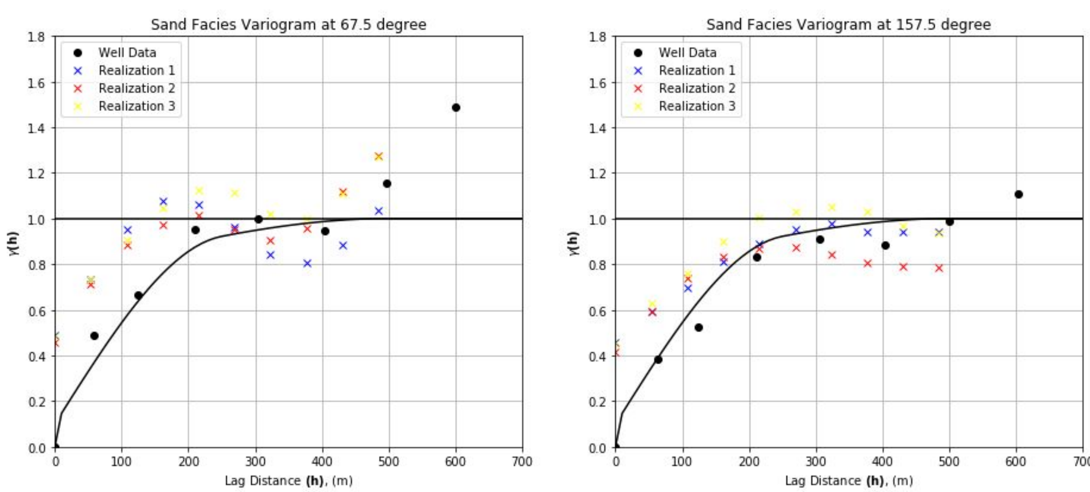

Figure 5. Variograms of simulated realizations of sand facies plotted along with well data

Porosity

Figure 6 shows the histograms of three realizations and the original data. It can be observed that the histograms look similar, and some differences possibly due to the inherent randomness in the realizations. Similarly, the variograms (Figure 7) of the realizations seem to honor the original variogram, with small ergodic fluctuations.

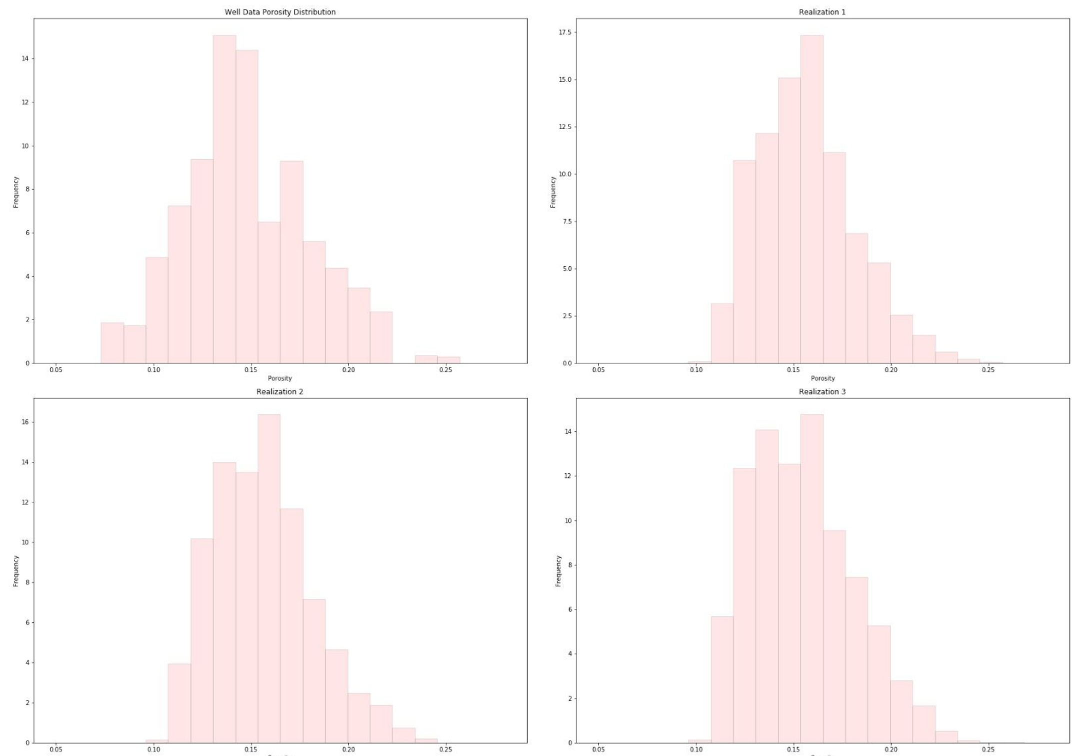

Figure 6. Porosity histograms for first three realizations compared with well data

The porosity variogram’s major and minor axes were 120 degrees and 30 degrees respectively, thus the corresponding x and y offsets were identified as 2 and 4 ,and 4 and -2 respectively.

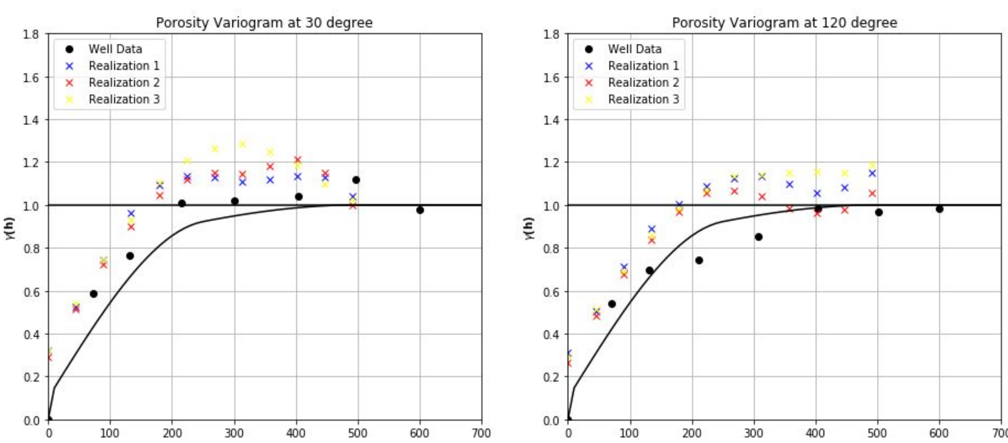

Figure 7. Variograms of simulated realizations of porosity plotted along with well data

Permeability

Figure 8 shows the histograms of three permeability realizations and the original permeability data. It can be observed that the histograms look similar, and some differences possibly due to the inherent randomness in the realizations. Similarly, the variograms of the realizations seem to honor the original variogram, with small ergodic fluctuations. The crossplots between porosity and permeability are shown in Figure 10. The bivariate relationship are also reproduced.

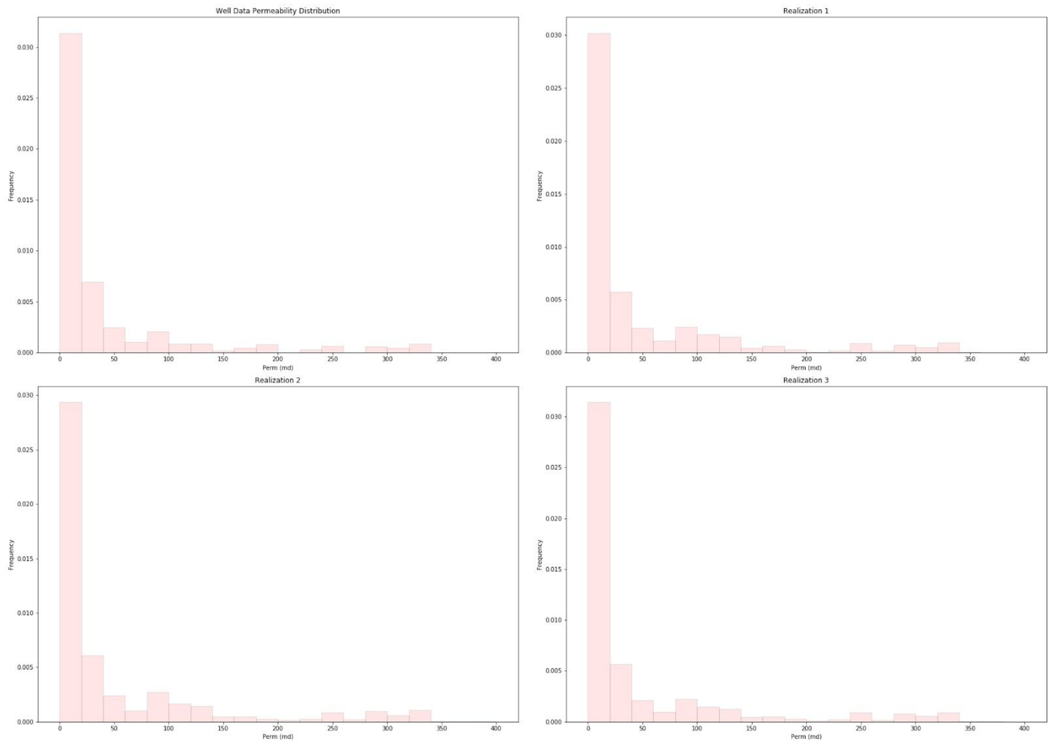

Figure 8. Permeability histograms for first three realizations compared with well data

The permeability variogram’s major and minor axes were 70 degrees and 160 degrees respectively, thus the corresponding x and y offsets were identified as 5 and -2 , and 2 and 5 respectively.

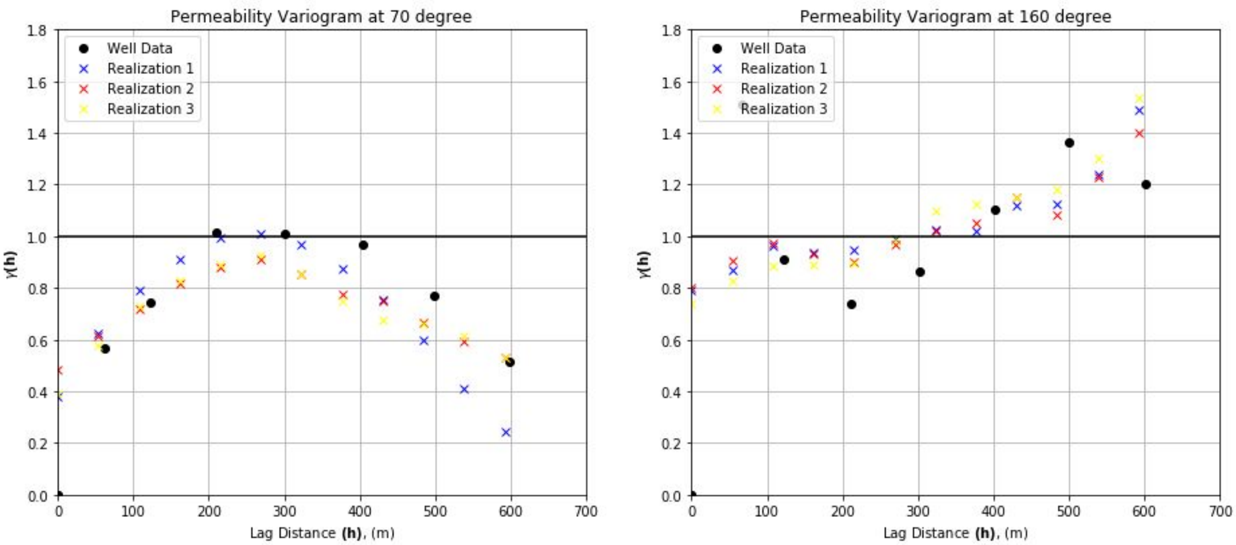

Figure 9. Variograms of cosimulated realizations of permeability plotted along with well data

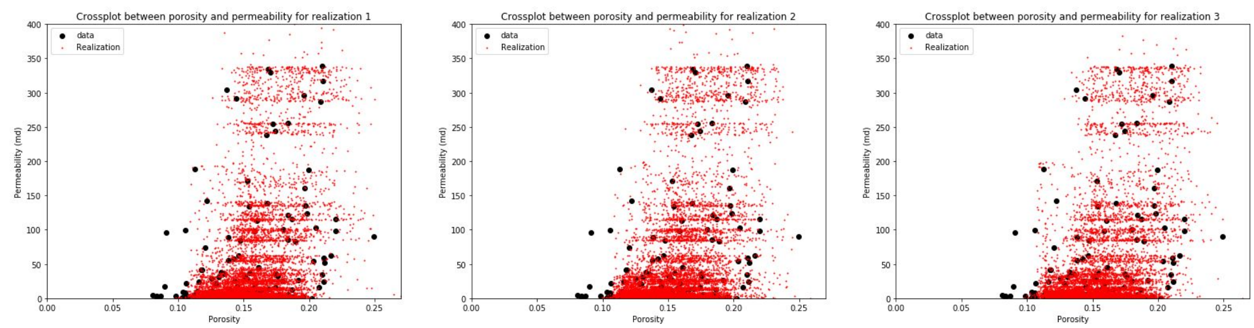

Figure 10. Crossplot between porosity and permeability from simulated realizations

- **Combined realization for porosity and permeability by facies**

Finally, all the realizations that were generated independently for each facies type, were combined using a cookie-cutter approach. For a given facies realization, if the probability of sand facies being present a given location was over 50 percent, that region was assigned the porosity and permeability values from the corresponding realizations for sand, and similarly for the case of shale facies. Figure 11 show three generated realizations based on this approach.

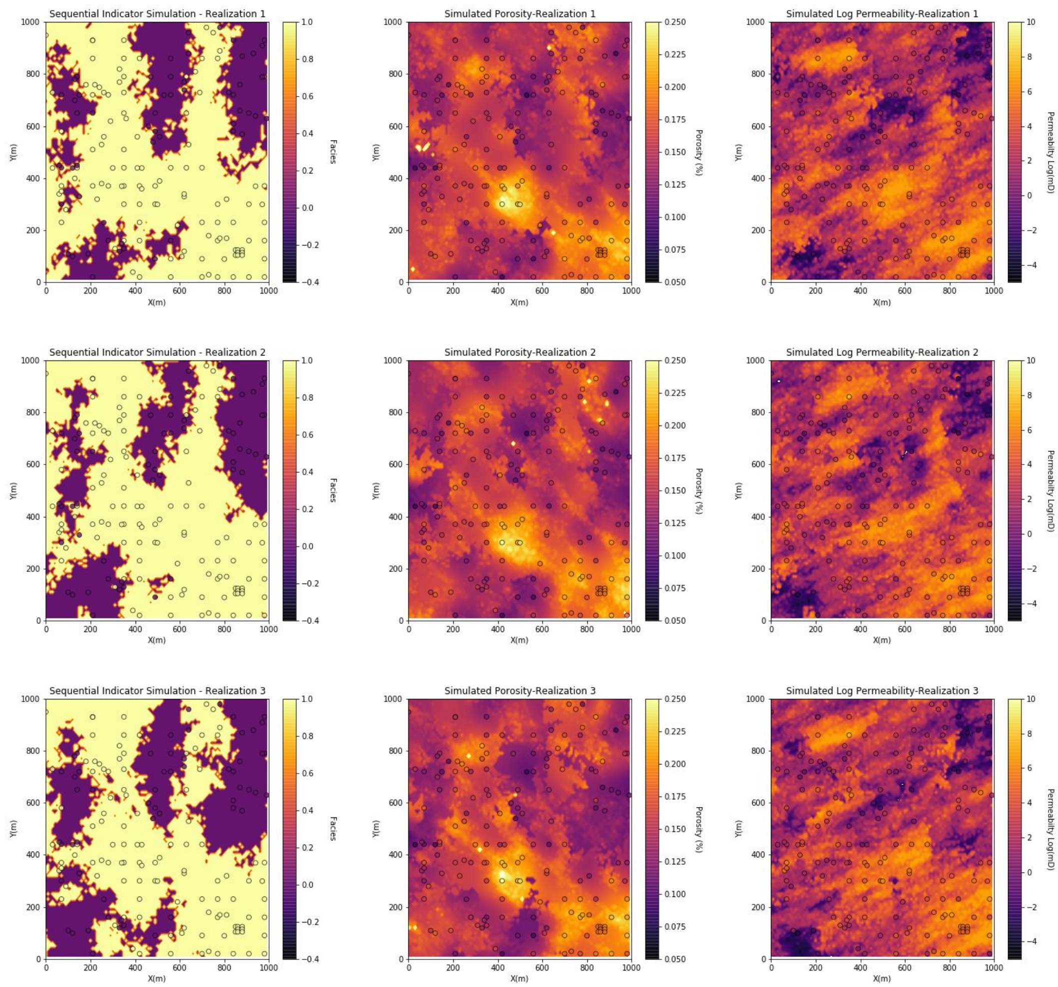

Figure 11. Examples of combined realization of simulated facies, porosity, and permeability

Conclusions

- Using simulation instead of kriging estimation helps us honor the data as well as the histogram and the spatial variability, while calculating a reasonably accurate estimation of the property at every point.
- Cosimulation proved to effectively account for the correlation between porosity and permeability
- The collocated cokriging methodology used for simulation permeability simulations is able to reproduce adequately the histograms and the variograms of the original permeability
- The input statistics (histogram and the variogram) of the various realizations generated after simulation of facies and porosity, show a good match as compared to the original data.

Future Work

- Perform post-processing subsurface realizations for uncertainty management
- Check our models to ensure they are consistent with all available data