Review of mini modeling and 3D conventional modeling in geostatistics with focus on McMurray data

Mohammad Mahdi Badiozamani, Yashar Pourrahimian, Mohammad Tabesh
Mining Optimization Laboratory (MOL)
University of Alberta, Edmonton, Canada

Abstract

Predicting the performance of in-situ recovery processes is required to optimize development planning and resource management in mining and petroleum projects. In this paper, two different concepts are presented; mini modeling and the 3D conventional modeling. In the first part of this paper, the mini modeling is discussed. In general, the mini modeling focuses on the porosity modeling of the formation in decimeter resolution. Then, the permeability is simulated through a number of realizations, and finally, the permeability is scaled up for the domain of interest through flow simulation. The mini modeling steps are implemented on a data set from the McMurray formation. In the second part, the steps of 3D conventional modeling are discussed and results from applying those steps to the data set from McMurray formation are illustrated. As the result of 3D conventional modeling, the porosity for different facies in the formation is both estimated and simulated through a number of realizations.

1. Introduction

This paper is divided into two parts: mini modeling and 3D conventional modeling. The mini modeling starts with section (2.1) about a survey on the characteristics of the data from McMurray formation, in terms of some statistics and histograms. Then, in section (2.2), the variogram, corresponding to each facies is calculated, followed by the variogram modeling. The simulation results for the porosity are discussed in section (2.3). Then, the permeability and flow simulation steps are discussed and the results for permeability and flow simulations are illustrated in section (2.4).

The 3D conventional modeling steps are discussed in the second part of the paper. In section (3.1), the facies proportions are calculated for each cell in the cubed grid. In section (3.2), the indicator variograms of facies are calculated, followed by the variogram modeling. After cross validating, the variogram models are used in the estimation and simulation of the facies in section (3.3). Section (3.4) starts with the declustering of the data points. Afterwards, based on the declustering weights, the variogram of porosity for each facies is calculated and modeled. The cross validation is done in order to check the goodness of variogram models as well. Estimation and simulation of porosity for each facies and the final porosity model are presented in section (3.5).The sample parameter files of GSLIB that are used in mini modeling and 3D conventional modeling are listed in the appendix section.

2. Mini Modeling

To do the geostatistical modeling some software are required. It is decided to use a set of free geostatistical tools as well as general software as mentioned in Table 1.

For mini modeling four steps should be done. These steps are as follows: (1) discussing the data characteristics, (2) calculation and modeling the porosity variogram only for one facies, the sandy IHS, (3) simulation of the porosity, and (4) simulation of the permeability and the flow.

Table 1. Required software

#	Software Name	Description	Website
1	Notepad ++	A professional open source text editor	http://Notepad-plus.sourceforge.net
2	Cygwin	A command prompt application based on Linux syntax	http://www.cygwin.com
3	SGeMS	A free set of geostatistical tools provided by Stanford university	http://sgems.sourceforge.net
4	GSLib	A free command based set of geostatistical tools by Clayton Deutsch and Manu Schnetzler.	http://gslib.com
5	MS Excel	A commercial spreadsheet used for doing some statistical operations and charting	http://office.microsoft.com

2.1. McMurray data characteristics

The data set used is a set of well logs data collected using 37 wells. Data have been measured along each well in 10 cm intervals. Wells are not distributed evenly over a large domain of 6000 by 2500 meters. Fig. 1 shows well locations. The domain of study is defined as a 6000*2500*78 m cube which is gridded by 50*50*1 m blocks. The facies parameter in the data file represents different facies. Table 2 shows the numbering scheme of the facies. The frequency of each facies is shown in Fig. 2.

Table 2. Facies numbering scheme

Number	Facies	Number	Facies
1	Sand	5	Breccia
2	Sandy IHS	6	Mud (plug)
3	Muddy IHS	7	Mud (bottom)
4	Mud (top)	9	Below or/and above the McMurray

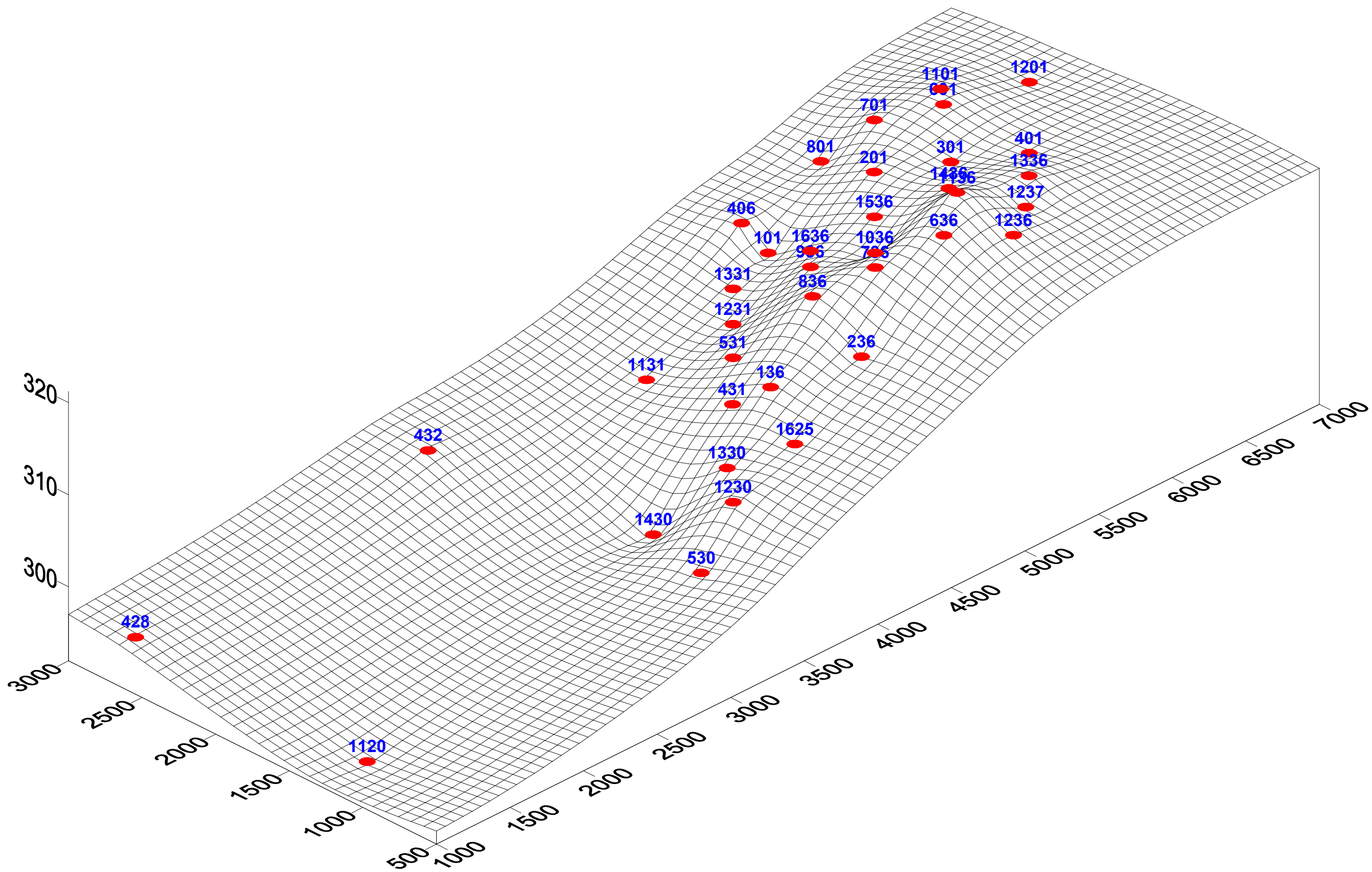


Fig. 1. Well locations and topology map of the study area

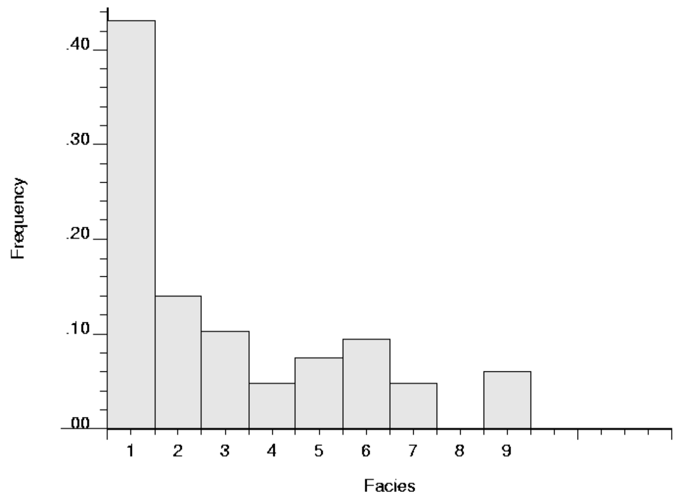


Fig. 2. Facies histogram

There are a number of fields in the database. The titles and a brief description of them are as follows:

- Well ID: the identification code of the wells.
- RX, RY and SZ: these three real numbers are the spatial coordinates of the well data in X, Y and Z orientations, respectively. The resolution of the measurements is decimeters.
- Elevation: a real number, representing the elevation from the sea level.
- Facies: an integer number, representing the code of facies Table 2. For later calculations, facies 9 is deleted, and then facies 4, 6 and 7 are all considered to be muddy shale and grouped together as a new facies, 4.
- Porosity: a real number, which represents the porosity of different facies. In the database, the points that their porosity has not been measured are reported to have the porosity of -1, which should be filtered in the calculations. Due to the precision of the measurement instruments, in some cases, the measured porosity is reported as “0”.
- Oil saturation: a real number, which represents the percent of oil saturation. 0 and -1 values have the same considerations as those of the porosity field.
- The porosity frequency histograms of facies are illustrated in Fig. 3.

As we want to do mini modeling for facies 2, this facies was more considered. Fig. 4 shows the top and bottom surfaces of facies 2 in the study area. It can be seen that the top surface is smoother than the bottom. Fig. 5 shows that well 428 does not cut the facies 2 and it can be an anomaly.

2.2. Variograms

Prior to calculating the experimental variogram, the data are transformed to normal scores, using the *NSCORE* command of *GSLIB*. The transformation is required, because the variograms will be used in the sequential Gaussian simulation (SGS), which requires variogram for normal scored values.

2.2.1 Variogram Calculation

The variogram is calculated for the facies 2, the sandy IHS. As noted in the data characteristics in section 1, there are some -1 as porosity values in the data set. These values are trimmed in the variogram calculation. Furthermore, since the trial variogram showed a very long range, only two meters is considered for variogram calculation and modeling. The variogram calculation parameters for vertical direction are presented in Table 3.

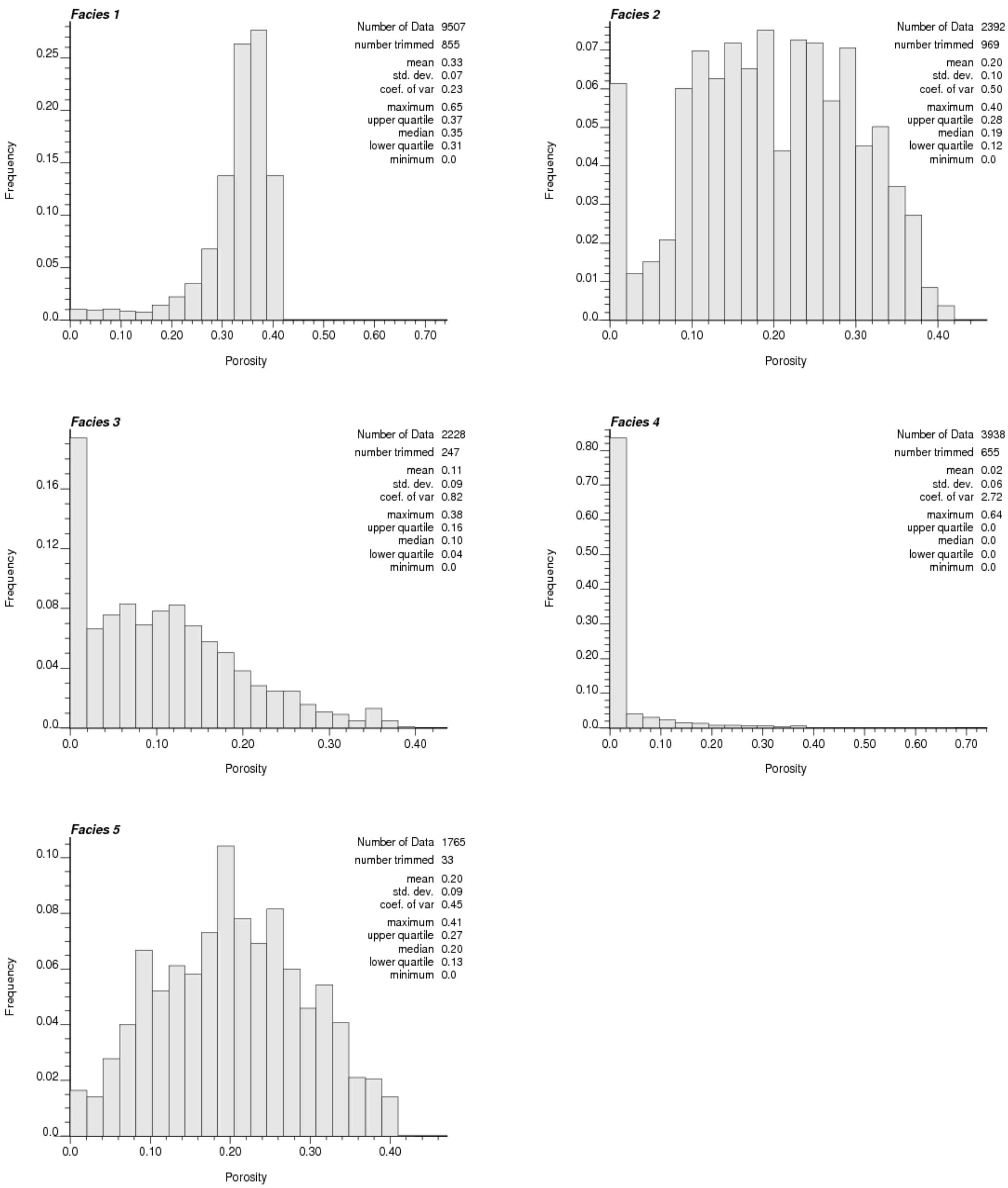


Fig. 3. Porosity distribution of facies

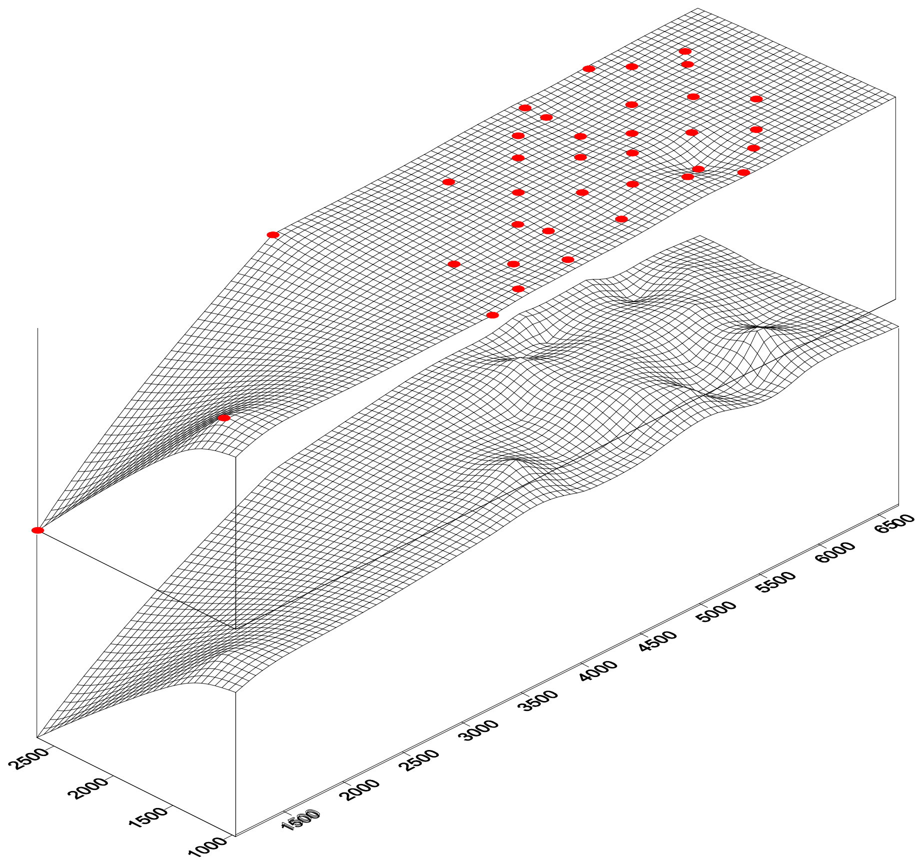


Fig. 4. top and bottom surface of facies 2 in the study area

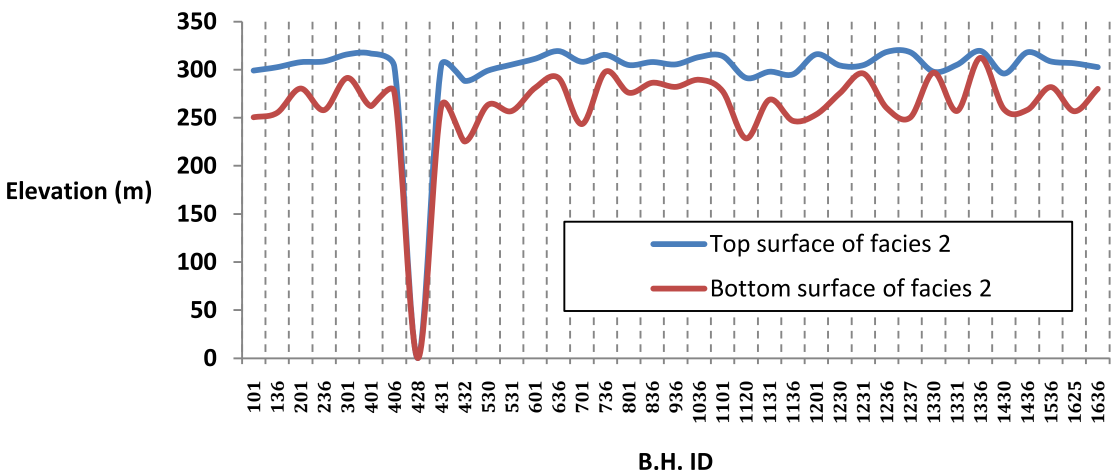


Fig. 5. Thickness of facies 2 in each well

Table 3. Variogram calculation parameters

parameter	value	parameter	value
Number of lags	200	Azimuth angle	
Lag separation	0.01m	Azimuth tolerance	
Lag tolerance	0.005m	Dip angle	
Calculation range	2 m	Dip tolerance	

2.2.2 Variogram Modeling

The nugget effect for the vertical variogram is approximately zero. In addition, since the actual range is high, the continuity of the porosity in the sandy IHS can be judged to be high.

The variogram is modeled, using the *VMODEL* command of *GSLIB*. The horizontal variogram is considered to have the same characteristics of the vertical variogram, with a range ratio of $a_{horz.} : a_{vert.} = 5:1$. It means that after modeling the vertical variogram, the horizontal variogram can be modeled only by changing the range. The variogram models are illustrated in Fig. 6. The red line represents the horizontal variogram, while the vertical variogram is illustrated with the blue line.

$$\gamma(h) = 0.39\, Sph_{\substack{a_{h\max}=3.5 \\ a_{h\min}=3.5 \\ a_{ver}=0.7}}(h) + 0.19\, Sph_{\substack{a_{h\max}=10 \\ a_{h\min}=10 \\ a_{ver}=2}}(h)$$

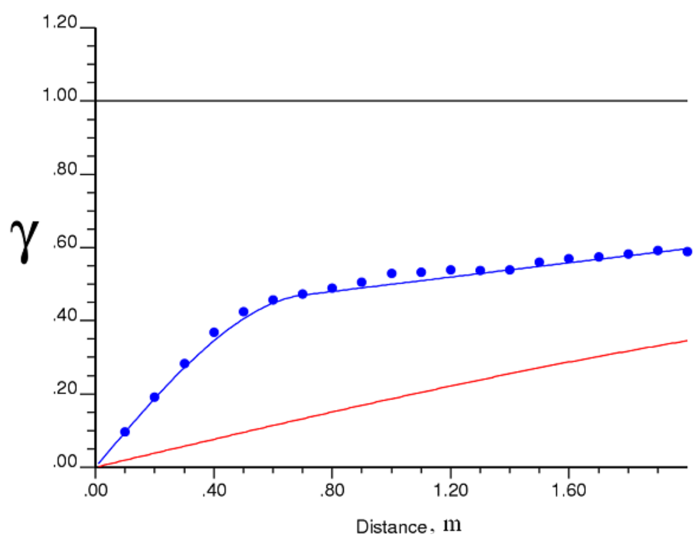


Fig. 6. Normal score variogram of well log scale porosity within the facies 2

2.3. Porosity Simulation

The porosity of the sandy IHS is simulated through 100 realizations. The horizontal and vertical variogram models are used in simulation. For simulation, the grid cells are defined $1\text{dm}\times 1\text{dm}\times 1\text{dm}$, within a cubic regular grid of $1\,m^3$. Since the simulation is done unconditionally, the results of simulation are in Gaussian units. (*SGSIM* command of *GSLIB* works this way). Therefore, the results of realizations should be back transformed to the original data units, between 0.0 and 0.4. It is done using *BACKTR* command of *GSLIB*. The back transformed results of the realizations are then averaged, using the *POSTSIM* command of *GSLIB*. The averaged result from the realizations is illustrated in Fig. 7.

In the process of averaging the simulation results, the averaged values violated the porosity limits in original data (0.0 to 0.4). That is because the *POSTSIM* command uses the first column of the input file, which is the back transformed data, but the first column of the back transform file is the original data, not the back-transformed! Therefore, first the back transform results should be refined and the first column should be omitted and then, the results should be passed to the *POSTSIM*. The results of the averaged simulations show the mean of 0.2, with the minimum and maximum of 0.18 and 0.22, respectively. The histogram of the post simulation results and histogram reproduction are shown in Fig. 8. The histogram reproduction in Fig. 8 shows that the histogram has been reproduced.

2.4. Permeability and Flow

To simulate the flow, firstly, the horizontal permeability should be simulated and then, using the $\frac{K_v}{K_h}$ ratio, the vertical permeability and the flow can be simulated.

2.4.1 Cloud Transformation; Permeability

Based on the simulation results for the porosity, the arithmetic average of porosity is calculated, using the *FLOWSIM* command of *GSLIB*. The summary statistics for the porosity are presented in Table 4.

Table 4. Statistics for porosity based on the flow simulation

statistics	value
minimum	
average	
maximum	
standard deviation	

To simulate the horizontal permeability flow, the cloud transformation and p-field simulated values are used. The p-field values are simulated through 100 realizations and unconditionally. The same variogram, as for the porosity is used for cloud transform as well. Then, for creating the bivariate distribution between porosity and horizontal permeability, the *BIMODEL* command of *GSLIB* is used. As the input, the *BIMODEL* requires the paired data points for porosity and horizontal permeability. These pairs are extracted from the results of micro modeling. The output of the *BIMODEL*, the bivariate distribution of porosity and the horizontal permeability, is illustrated in Fig. 9.

The bivariate distribution and the porosity values (simulation results that are back transformed to the original scale) are then used in cloud transformation. The cloud transformation is performed to find the horizontal permeability values, based on the porosity values, the p-field values and the bivariate distribution of porosity and horizontal permeability.

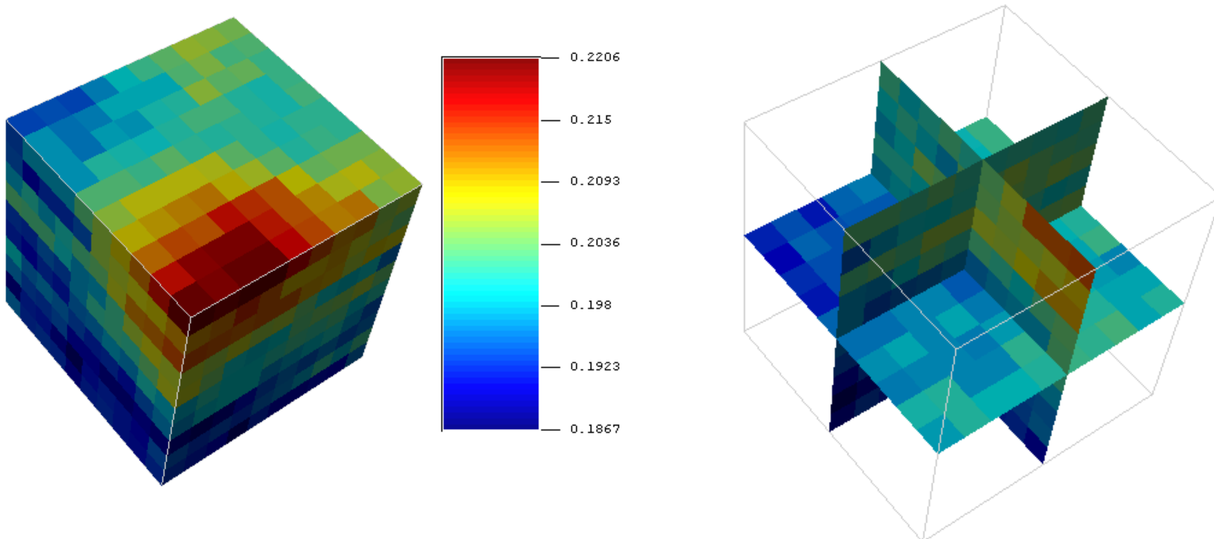


Fig. 7. simulation results for porosity, sandy IHS

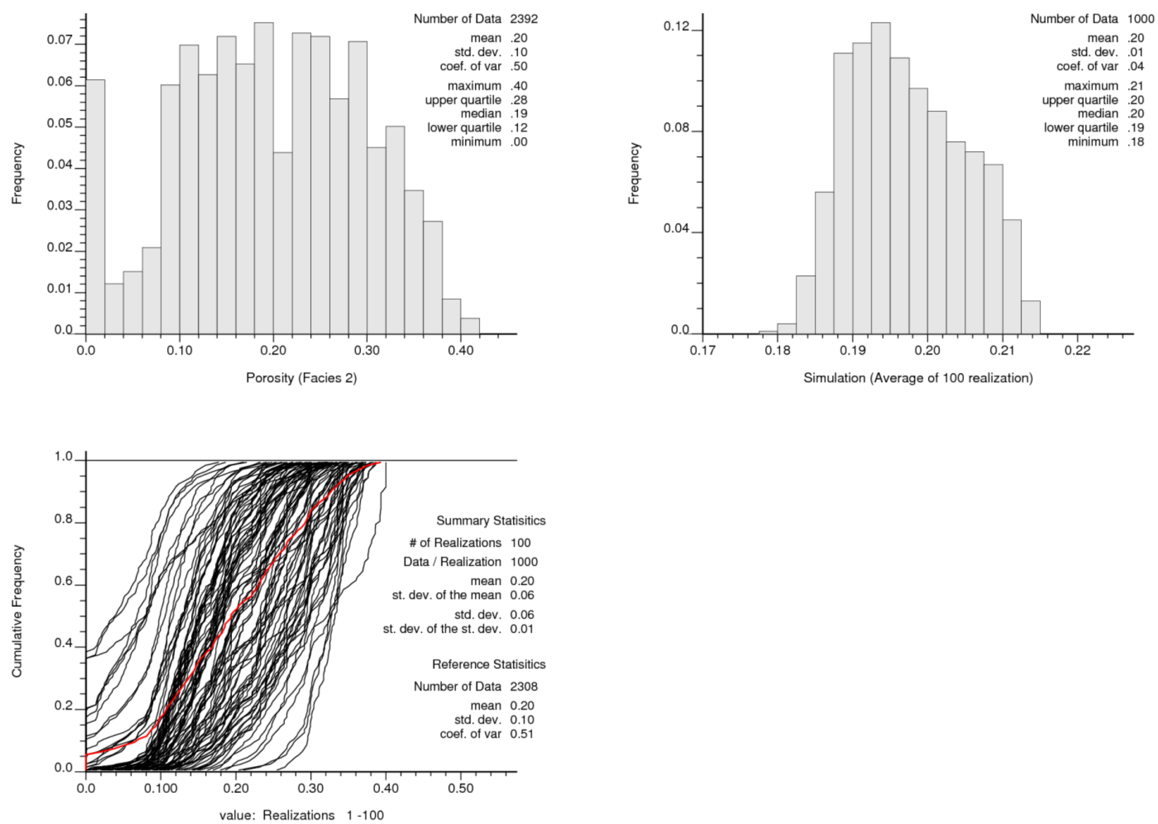


Fig. 8. Histogram of porosity for facies 2 and histogram of average of 100 realizations referenced to the distribution of porosity of facies 2

The horizontal permeability values are simulated through 100 realizations, using the *CLTRANS* command of *GSLIB*. Then, the simulated values are averaged, using the *POSTSIM* command. The average of simulated values is illustrated in Fig. 10.

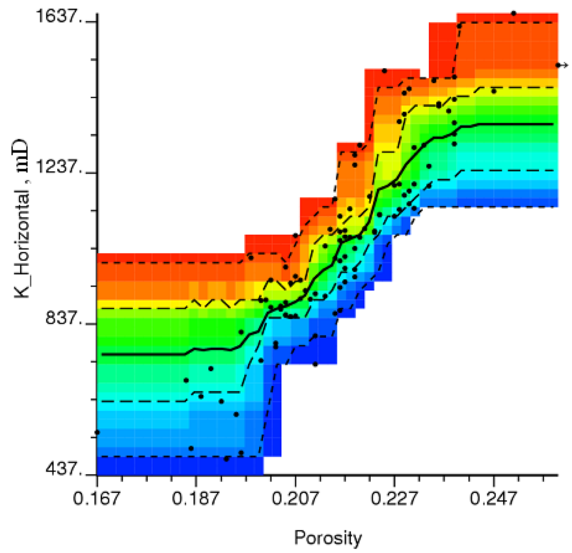


Fig. 9. The bivariate distribution of porosity and horizontal permeability

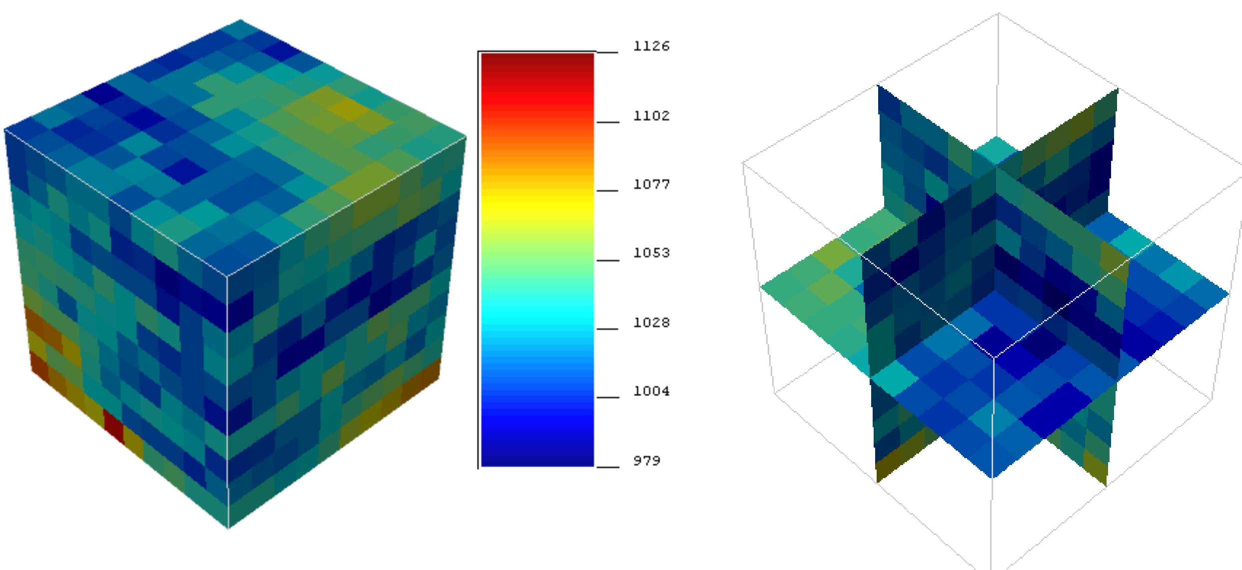


Fig. 10. Simulation result for horizontal permeability

The average of the $\frac{K_v}{K_h}$ ratio, based on the outputs of micro modeling, equals to 1.927. Using this ratio, the values for vertical permeability are calculated. The summary statistics of the permeability values is presented in Table 5.

2.4.2 Flow simulation

The simulation results for the horizontal and vertical permeability now can be used for flow simulation. The flow is simulated through 100 realizations, using the FLOWSIM command of GSLIB. The resulting values from flow simulation are illustrated as cross plots in Fig. 11. The summary statistics corresponding to the flow simulation results are presented in Table 6.

Table 5. Statistics of permeability simulation

	minimum	maximum	average	standard deviation
Vertical permeability (mD)	843	3199	1993	623
Horizontal permeability (mD)	437	1660	1034	323

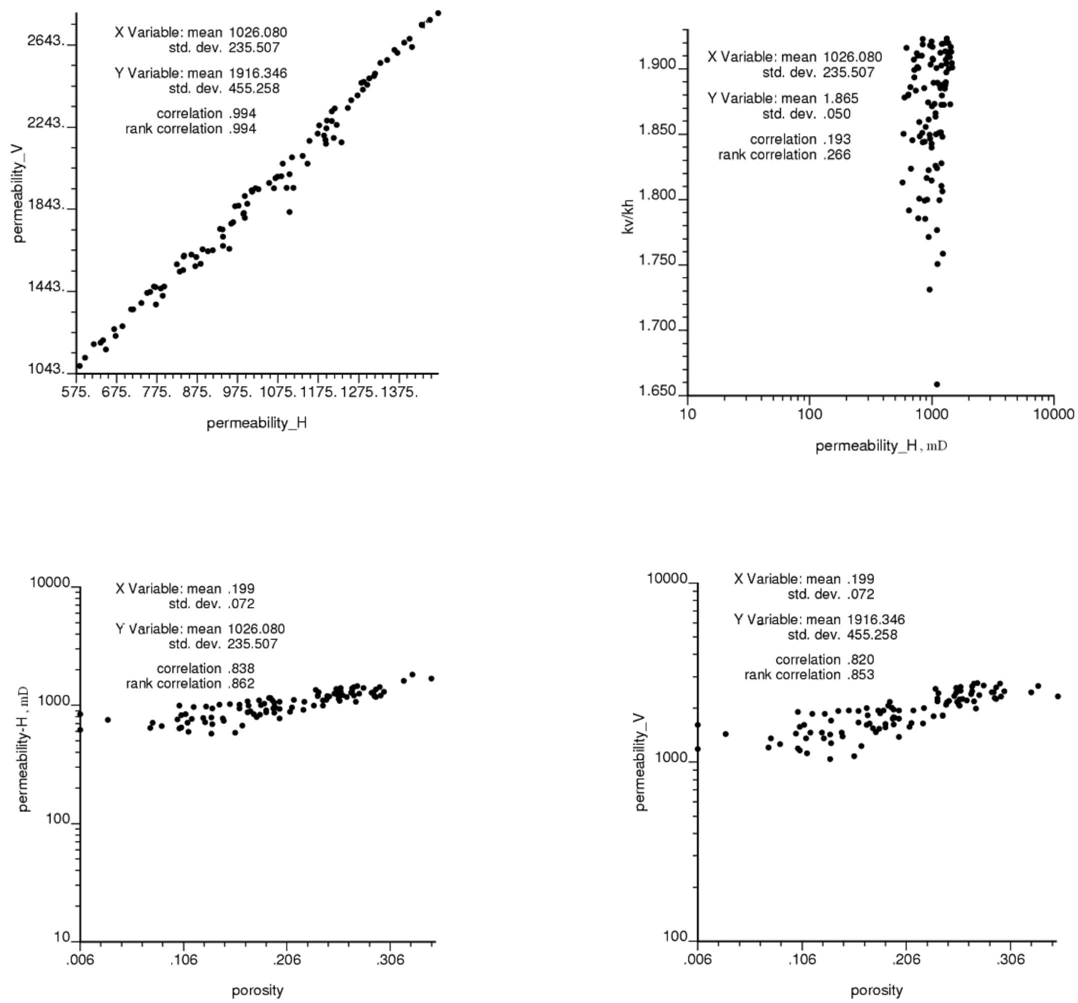


Fig. 11. Cross plot of obtained results from FLOWSIM

Table 6. Summary statistics of flow simulation results

variable	minimum	maximum	mean	Standard deviation
(mD)	1043	2798	1916	455
(mD)	575	1472	1026	236
Kv/Kh	1.65	1.93	1.87	0.05
Correlation coefficients				
vs. :	0.99	—vs. :		0.19
porosity vs. :	0.84	porosity vs. :		0.82

3. 3D Conventional Modeling

For 3D conventional modeling five steps should be done. These steps are as follows: (1) calculation of facies proportions, (2) calculation and modeling the facies indicator variograms and cross validation of the variogram models, (3) estimation and simulation of facies indicators, (4) declustering of the data points and porosity variogram calculation and modeling, and (5) estimation and simulation of porosity for each facies and building the porosity model.

3.1. 3D Proportion Cube of Facies

The facies proportions can be calculated in both vertical and areal directions. In the vertical direction, the proportions are calculated based on the values of all facies at each elevation (from 0 to -78 meter). The resulting proportion charts are illustrated in Fig. 12.

For the areal proportions, the areal trend is estimated, using the *KT3D* command of *GSLIB*. In order to estimate the trend, a variogram with a very large range, approximately equal to one third of the domain in each direction, is used. The nugget that is used for the trend model variogram is 30 percent of the sill. The grid system specifications are presented in Table 7. The areal trend maps for different facies are illustrated in Fig. 13.

Table 7. The grid specifications for the 3D conventional modeling

	Min (m)	Max (m)	specified range (m)	cell size (m)	No. of cells
X direction	1100	6679	6000	50	120
Y direction	972	2644	2500	50	50
Z direction	-78	0	78	1	78

The vertical proportions and the areal trend maps are merged together to make the “proportion cube” of facies. The theoretical background of combining proportions is based on the probability combination schemes that approximates the probability of geologic event jointly conditioned to diverse data sources through combining the calibrated probabilities conditioned to individual data source (Hong and Deutsch, 2009). Integrating the vertical and horizontal proportion that may be modeled by different data sources can be viewed as a probability combination problem. Consider the proportion of facies k in (x,y,z) location $P_k(x,y,z)$ given the areal proportion $P_k(x,y)$ and the vertical proportion $P_k(z)$, k=1,…,5. The $P_k(x,y,z)$ can be estimated as following:

$$P_K(x,y,z) = \left(\frac{P_K(x,y)}{P_K}\right).\left(\frac{P_K(z)}{P_K}\right).P_K$$

Where P_k is the global proportion of facies k. The merging is performed, using the *PCSTM* command of *GSLIB*. 3D cross sectional views of the resulting cube for each facies are illustrated in Fig. 14. For better visualization, the elevation -"Z" direction- is scaled up to 20. The global proportions are 0.46, 0.15, 0.11, 0.22 and 0.07 for facies 1 to 5.

3.2. Variogram of Facies

The indicator variogram for each facies is calculated, using *GAMV* command of *GSLIB*. Then, the variogram for each facies is modeled.

The indicator variogram in vertical direction is calculated for all five facies. Since the horizontal variograms do not show any specific behavior, it is not possible to fit a model for them. On the other hand, according to the geology of the specific domain, the ratio of variogram ranges is approximately equal to $a_{horz.} : a_{vert.} = 100:1$. Vertical variogram is modeled and then, for the horizontal variogram, the same vertical model is used with the only change in the range. Variogram calculation parameters for vertical direction are presented in Table 8.

Table 8. Facies indicator variogram calculation parameters

parameter	value	parameter	value
Number of lags	50	Azimuth angle	
Lag separation	0.4m	Azimuth tolerance	
Lag tolerance	0.05m	Dip angle	
Calculation range	20 m	Dip tolerance	

Table 9 contains the parameters used for variogram modeling in vertical direction. The variogram is modeled, using the *VMODEL* command of *GSLIB*. The horizontal variogram is considered to have the same characteristics of the vertical variogram, with a range ratio of $a_{horz.} : a_{vert.} = 100:1$. It means that after modeling the vertical variogram, the horizontal variogram can be modeled only by changing the range. The vertical variogram models are illustrated in Fig. 15.

In order to check the goodness of the variogram models, the cross validation is performed, using the *KT3D* command of *GSLIB*. For the cross validation, the 3D trend proportion cube is required. In addition, the stationary assumption should not be considered in kriging for the cross validation, because the variance changes over the domain and the homoscedastisity is not met. The results of cross validation are then compared with the original data to check the reproducibility of the data, using the variogram model. The correlation coefficients and the slope of the regression line in each case are reported in Table 10. The cross plots of original data versus the estimated data are illustrated in Fig. 16.The results show that the variogram models are acceptable.

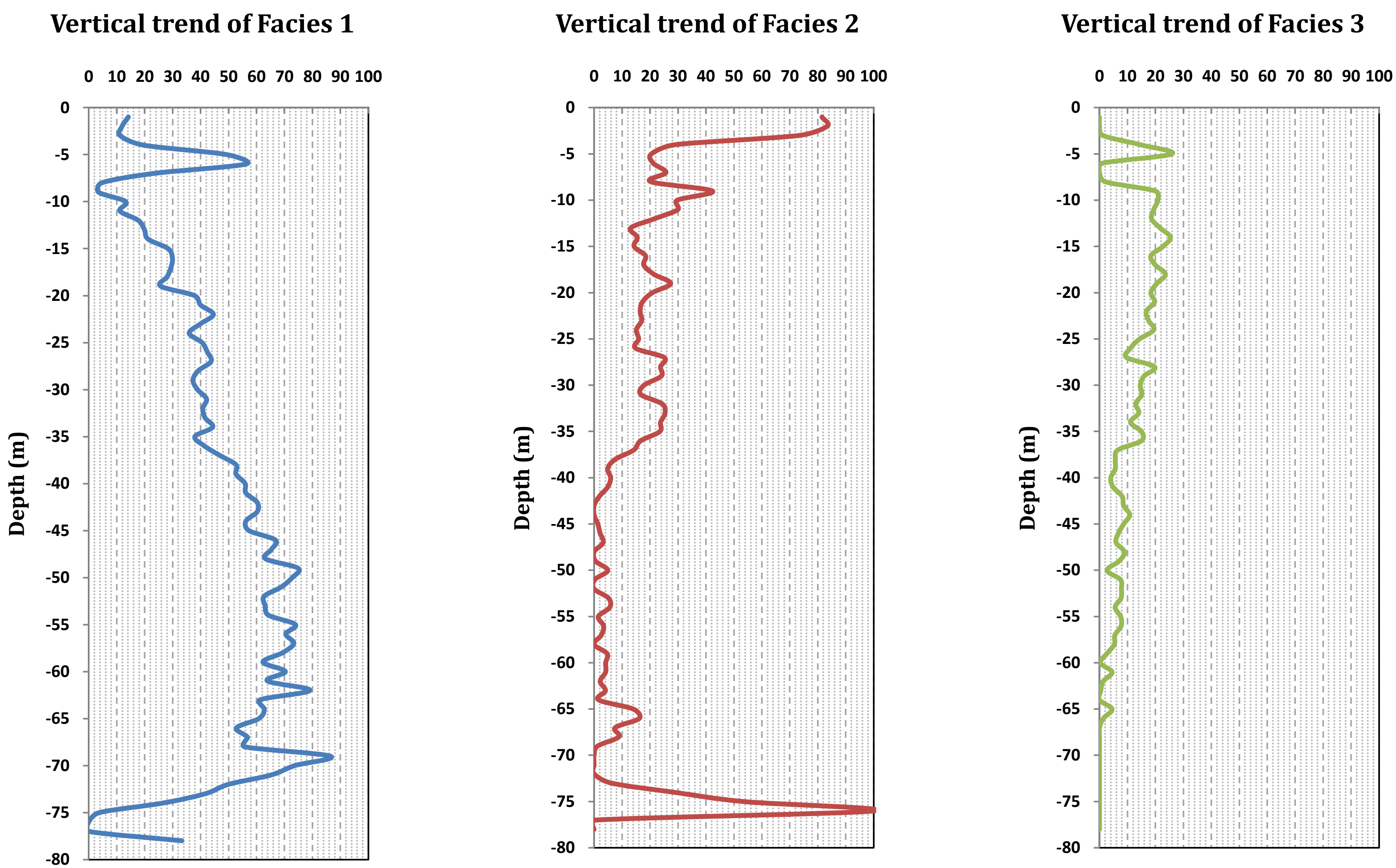
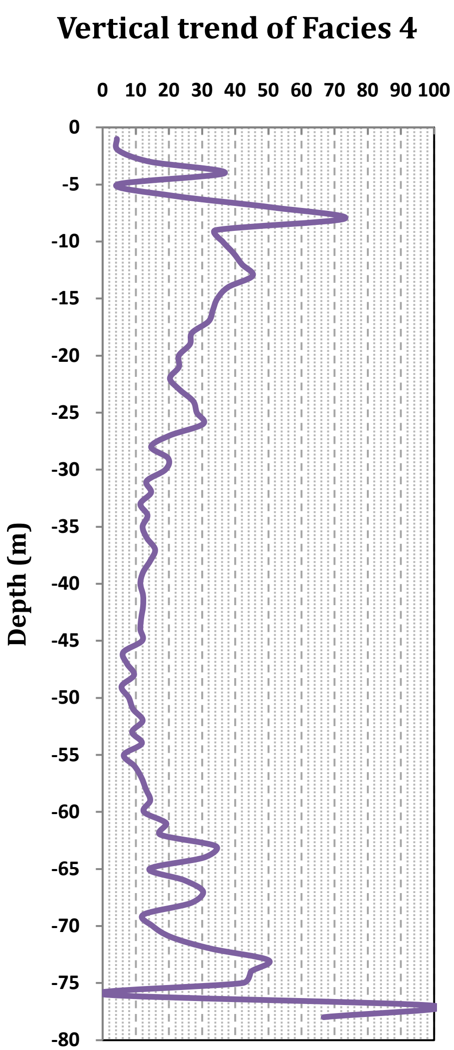


Fig. 12. Vertical trend for each facies



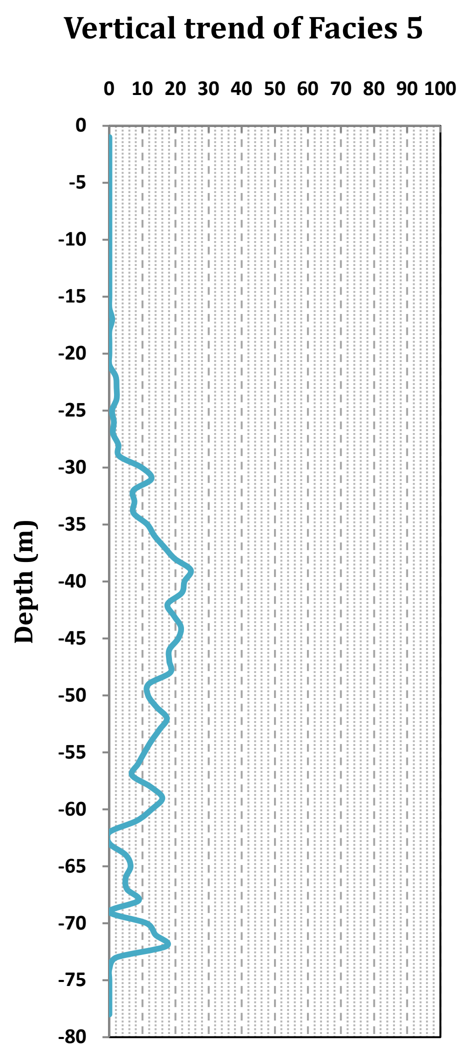
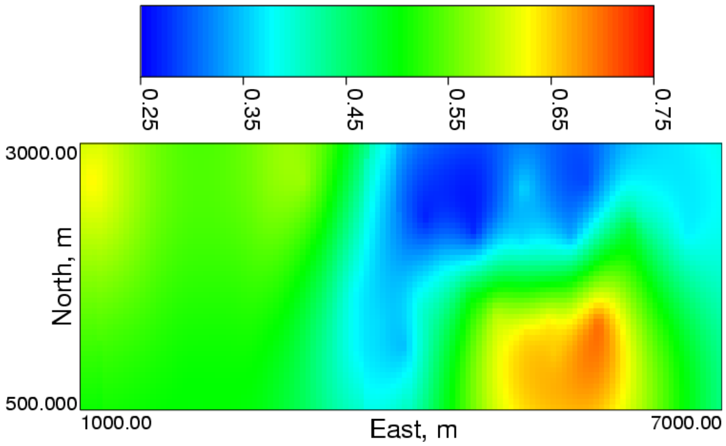
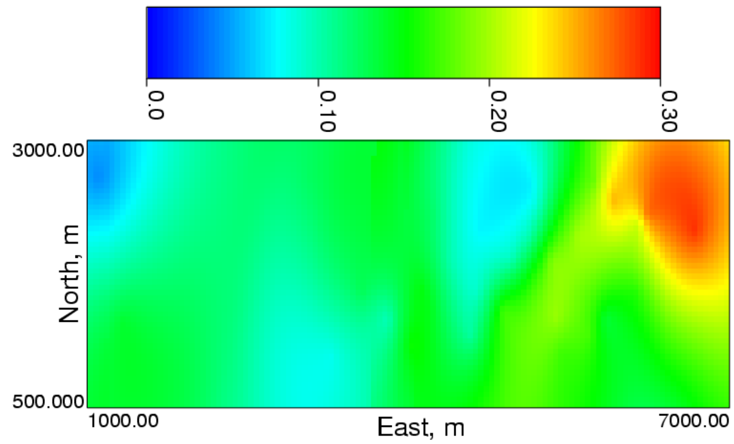


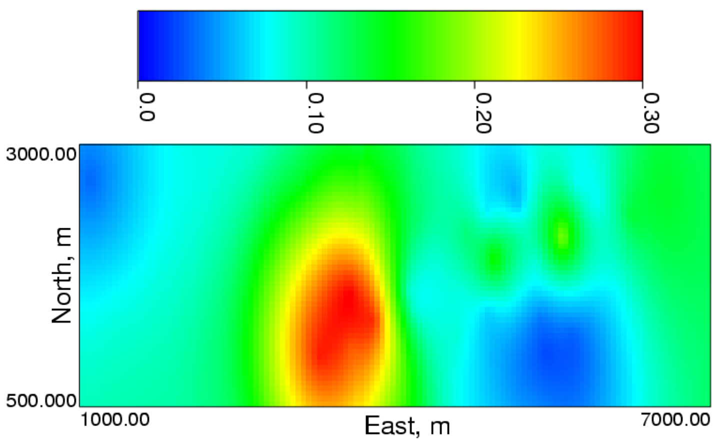
Fig. 12, Continued



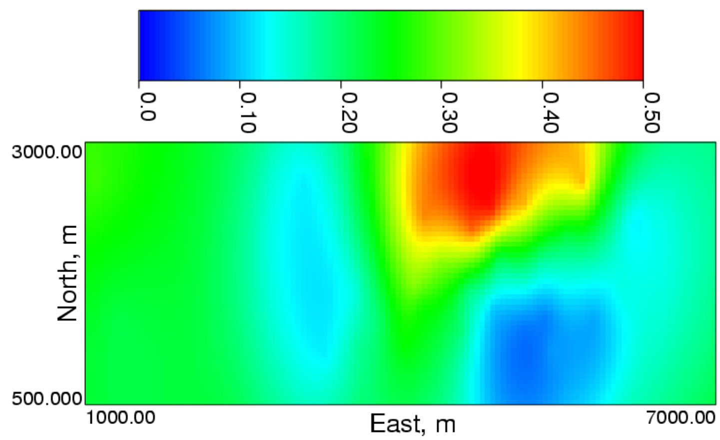
(a) facies 1



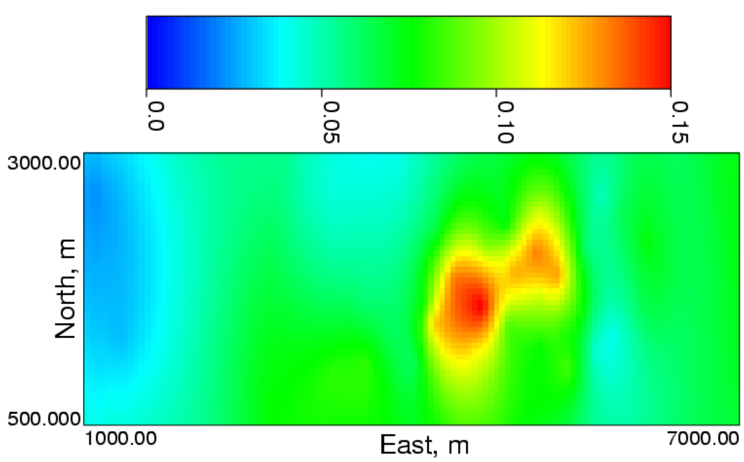
(b) facies 2



(c) facies 3

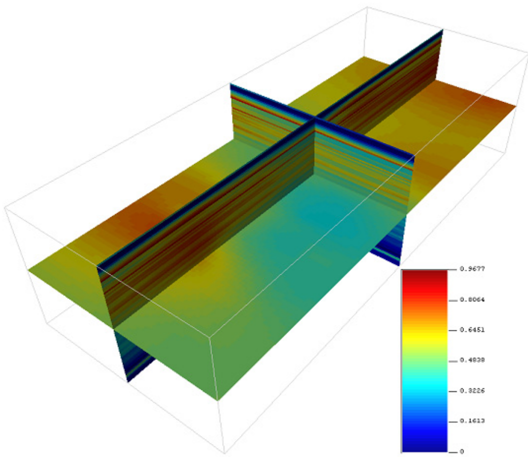


(d) facies 4

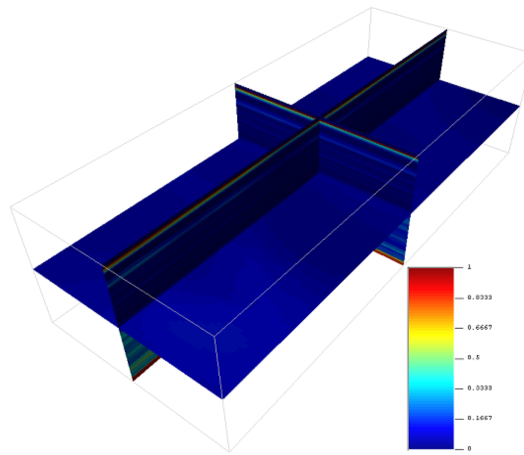


(e) facies 5

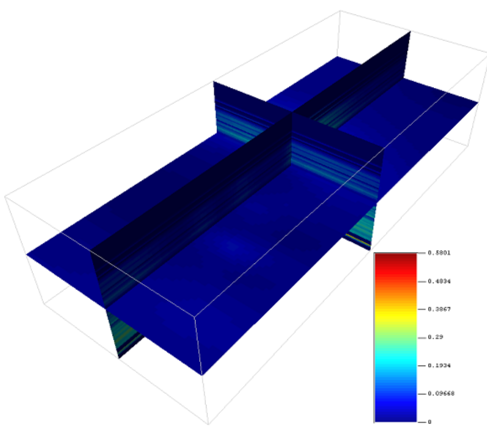
Fig. 13. The areal trend map of different facies



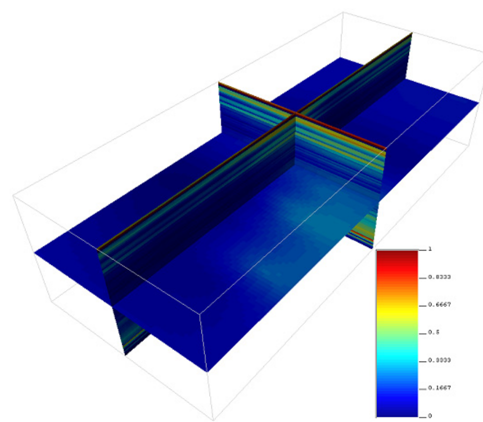
(a) facies 1 (range:0 – 0.97)



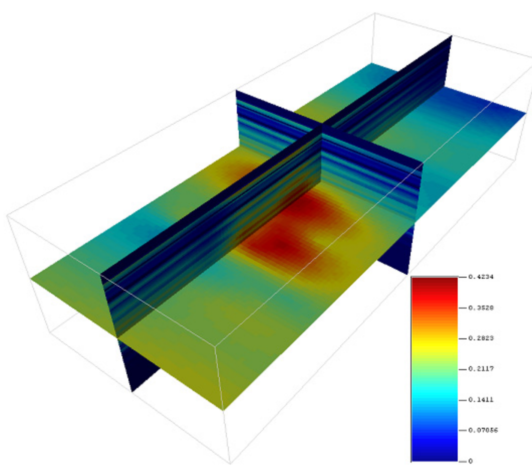
(b) facies 2 (range:0 – 1.0)



(c)facies 3 (range:0 – 0.58)



(d) facies 4 (range:0 – 1.0)



(e) facies 5 (range:0 – 0.42)

Fig. 14. The proportion cube of facies

Table 9. Parameters for facies variogram modeling

facies	Structure #	Structure type	contribution	Range (vert.), m	Range (Hor.), m
1	1	nugget	0.10	N/A	N/A
	2	spherical	0.55	6	600
	3	spherical	0.35	30	3000
2	1	nugget	0.20	N/A	N/A
	2	spherical	0.50	5	500
	3	spherical	0.30	25	2500
3	1	nugget	0.10	N/A	N/A
	2	spherical	0.80	7.5	750
	3	spherical	0.10	20	2000
4	1	nugget	0.10	N/A	N/A
	2	spherical	0.70	9	900
	3	spherical	0.20	120	12000
5	1	nugget	0.20	N/A	N/A
	2	spherical	0.78	6	600
	3	spherical	0.02	13	1300

Table 10. Cross validation summary for facies variogram

Facies	correlation coefficient	regression slope
1	0.95	1.033
2	0.94	1.059
3	0.96	1.035
4	0.95	1.034
5	0.92	1.064

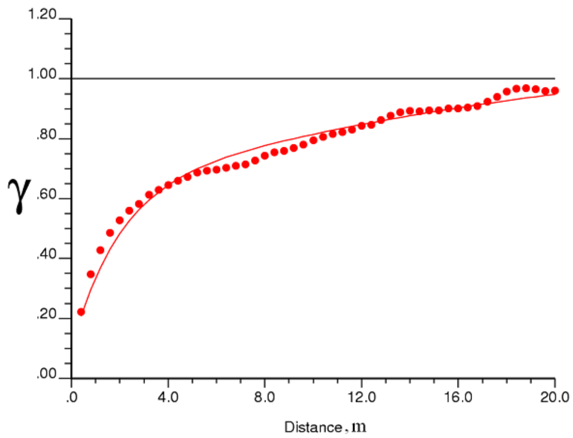
3.3. Facies Estimation and Simulation

The same adjustments and configurations are considered in estimating the facies as those used in cross validation. The results from kriging are visualized, using *SGEMS* and illustrated in Fig. 17. The family of red colors represents the presence of the facies in the area.

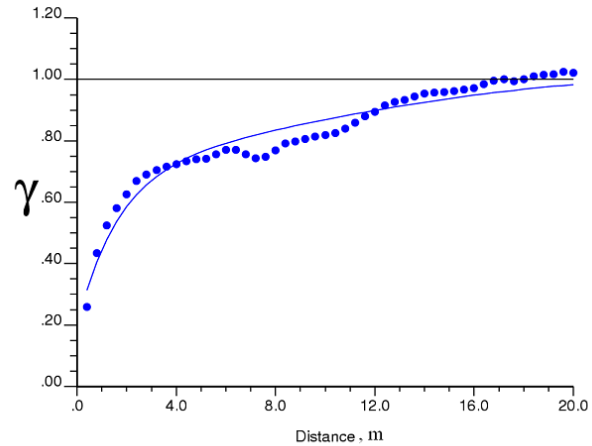
The facies are simulated through 100 realizations, using the *BLOCKSIS* command of *GSLIB*. In order to simulate the facies, it is required to put the 3D trend proportion cube as input.

3.4. Variogram of Porosity

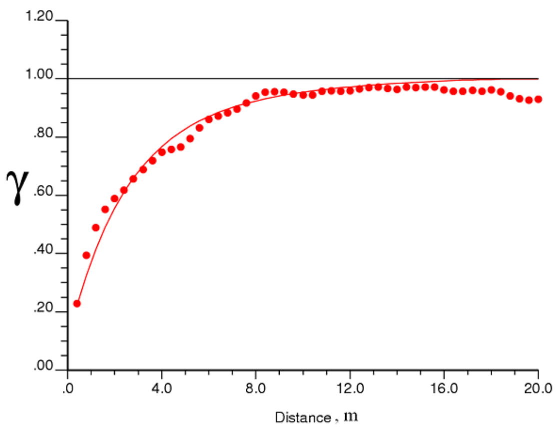
Prior to calculating the experimental variograms for porosity, the data is declustered, using *DECLUS* command of *GSLIB*.



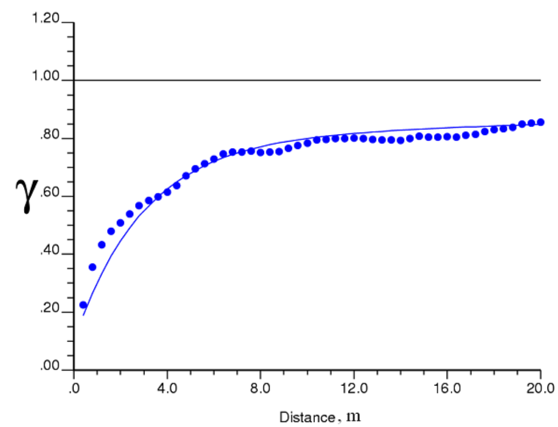
(a) facies 1



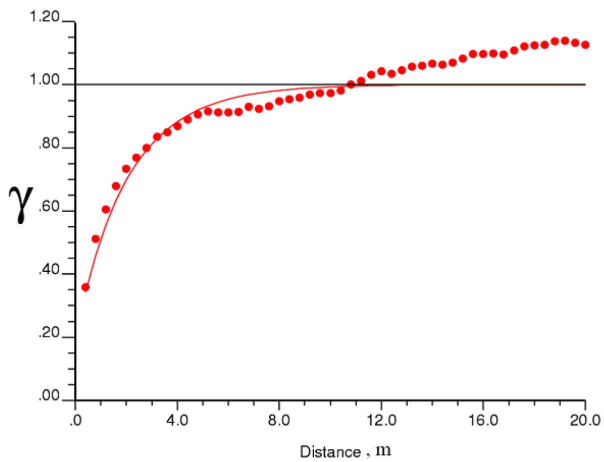
(b) facies 2



(c) facies 3



(d) facies 4



(e) facies 5

Fig. 15. Vertical variogram models for five facies

3.4.1 Declustering

Since the data points are located on a regular grid in Z direction (equal intervals of 1 m), the declustering is performed only based on X and Y coordinates. The declustering cell size is 0.211 m. The porosity frequency histograms of facies, resulted from declustering, are illustrated in Fig. 18. The summary statistics for each facies is presented in Table 11.

Then, the data are transformed to normal scores, using the *NSCORE* command of *GSLIB*. The transformation is required, because the variograms will be used in the sequential Gaussian simulation (SGS) which requires variogram for normal scored values.

3.4.2 Variogram calculation

The vertical variogram of porosity is calculated for all facies. The variogram calculation parameters for vertical direction are presented in Table 12.

3.4.3 Variogram modeling

The vertical variograms are modeled, based on the experimental variograms. For horizontal variograms, the same ratio of $a_{horz.} : a_{vert.} = 100:1$ is used, as in facies variograms.

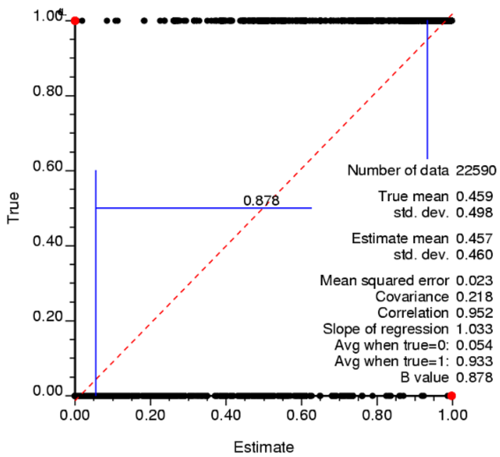
Table 13 includes the parameters used for variogram modeling in vertical and horizontal directions. The variograms are modeled, using the *VMODEL* command of *GSLIB*. The horizontal variogram is considered to have the same characteristics of the vertical variogram, with a range ratio of $a_{horz.} : a_{vert.} = 100:1$. It means that after modeling the vertical variogram for each facies, the horizontal variogram can be modeled only by changing the range. The variogram models are illustrated in Fig. 19.

Table 11. The porosity statistics for different facies

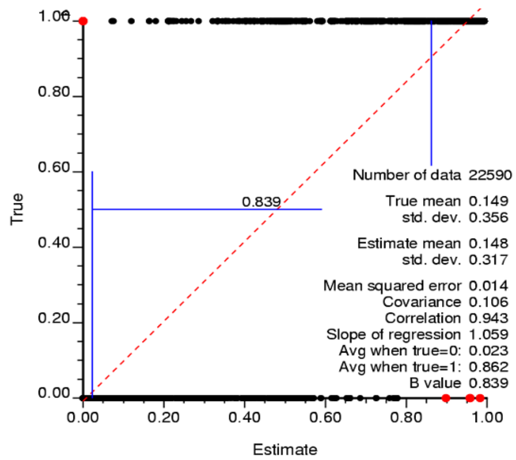
	Facies 1 (sand)	Facies 2 (sandy IHS)	Facies 3 (muddy IHS)	Facies 4 (muddy shale)	Facies 5 (breccia)
number of data	9507	2392	2228	3938	1765
average		0.20	0.11	0.02	0.20
standard deviation	0.07	0.10	0.09	0.06	0.09
coefficient of variation	0.23	0.50	0.82	2.72	0.45
maximum	0.65	0.40	0.38	0.64	0.41

Table 12. The porosity variogram calculation parameters

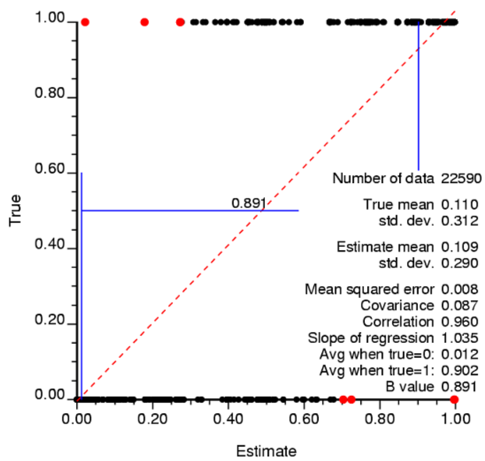
parameter	value	parameter	value
Number of lags	25	Azimuth angle	
Lag separation	1 m	Azimuth tolerance	
Lag tolerance	0.5 m	Dip angle	
Calculation range	2 m	Dip tolerance	



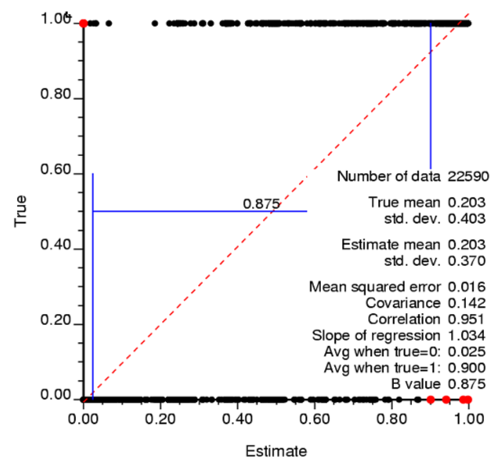
(a) facies 1



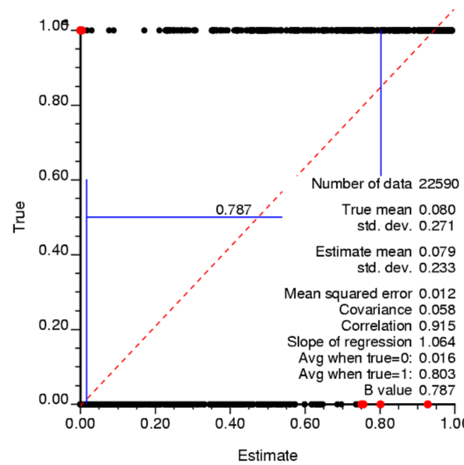
(b) facies 2



(c) facies 3

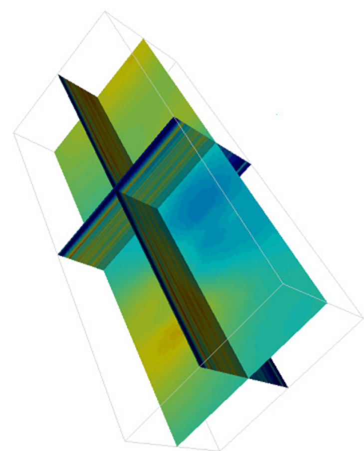


(c) facies 4

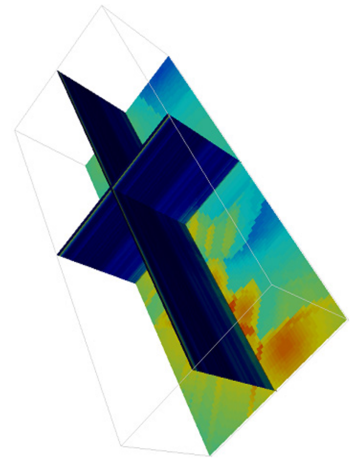


(e) facies 5

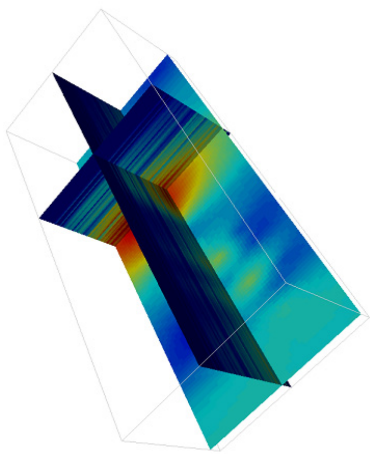
Fig. 16. Cross validation results for facies



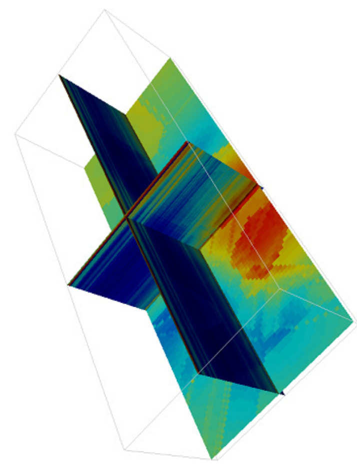
(a) facies 1



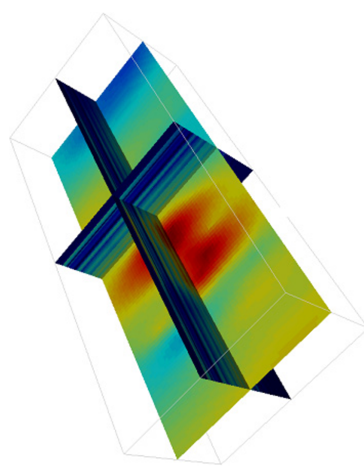
(b) facies 2



(c) facies 3

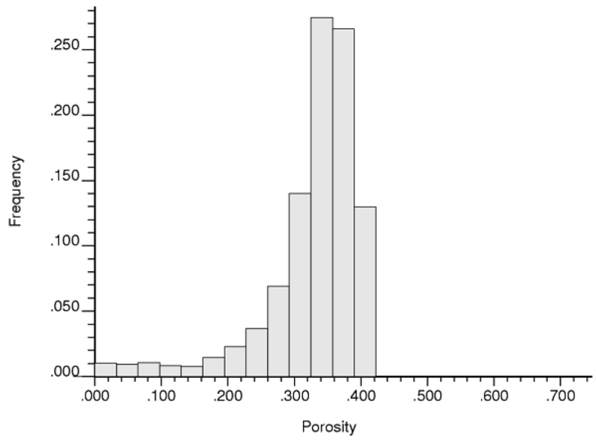


(d) facies 4

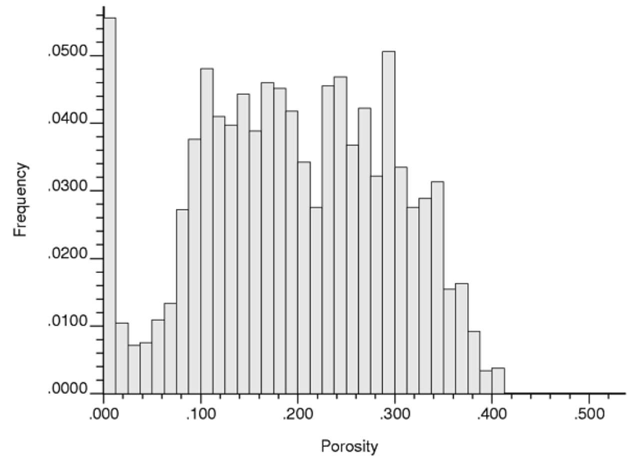


(e) facies 5

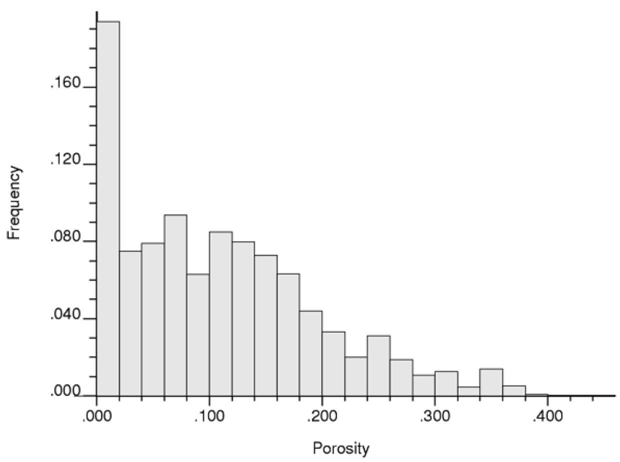
Fig. 17. The results from facies kriging



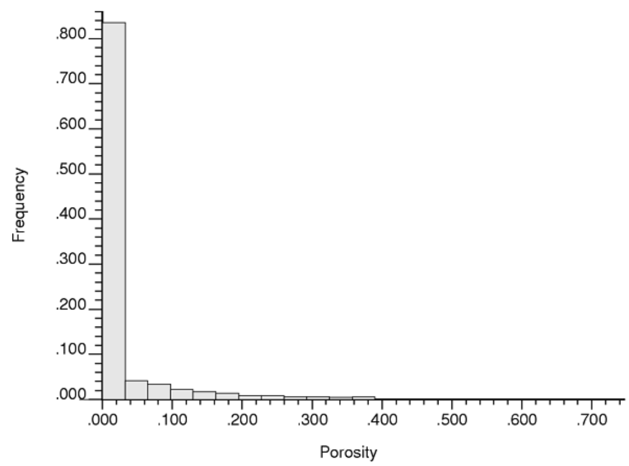
(a) facies 1



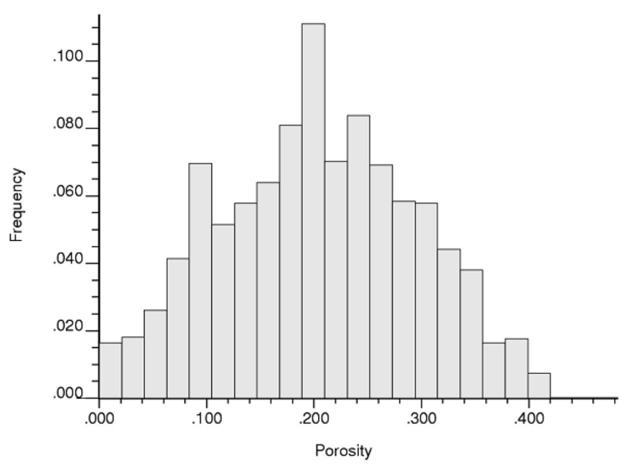
(b) facies 2



(c) facies 3



(d) facies 4



(e) facies 5

Fig. 18. Porosity distribution of the facies

Table 13. Parameters for porosity variogram modeling

facies	Structure #	Structure type	contribution	Range (vert.), m	Range (Hor.), m
1	1	nugget	0.10	N/A	N/A
	2	spherical	0.57	5	500
	3	spherical	0.33	45	4500
2	1	nugget	0.20	N/A	N/A
	2	spherical	0.47	7	700
	3	spherical	0.33	30	3000
3	1	nugget	0.10	N/A	N/A
	2	spherical	0.42	11	1100
	3	spherical	0.48	20	2000
7	1	nugget	0.52	N/A	N/A
	2	spherical	0.26	8	800
	3	spherical	0.22	50	5000
5	1	nugget	0.30	N/A	N/A
	2	spherical	0.50	7	700
	3	spherical	0.20	20	2000

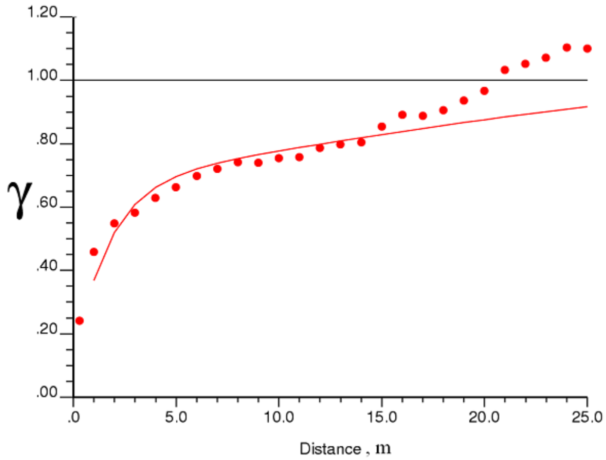
In order to check the goodness of the variogram models, the cross validation is performed, using the $KT3D$ command of $GSLIB$. For the cross validation, the 3D trend proportion cube is required. In addition, the stationarity assumption should not be considered in kriging for the cross validation as the variance changes over the domain, and the homoscedastisity is not met. The results of cross validation are then compared with the original data to check the reproducibility of the data, using the variogram model. The correlation coefficients and the slope of the regression line in each case are reported in Table 14. The cross plots of original data versus the estimated data are illustrated in Fig. 20.

Table 14. Cross validation summary for porosity variogram

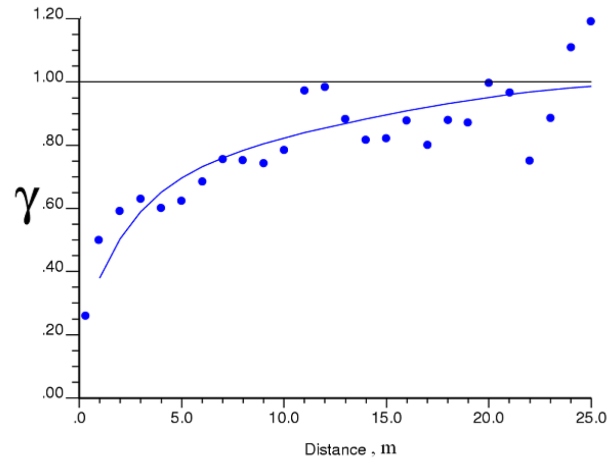
Facies	correlation coefficient	regression slope
1	0.92	1.047
2	0.90	1.078
3	0.90	1.044
4	0.64	1.071
5	0.81	1.162

3.5. Porosity Estimation and Simulation (The Porosity Model)

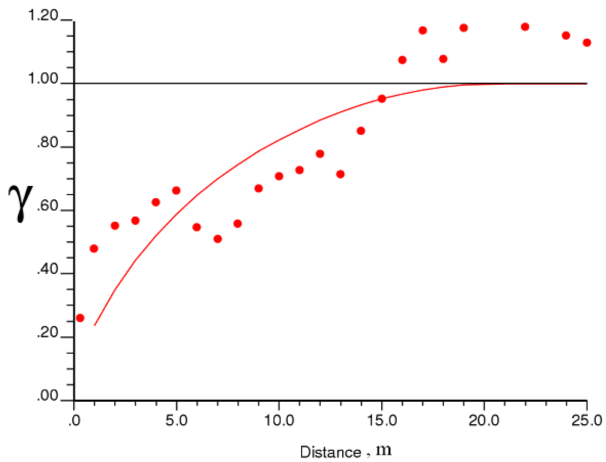
The porosity is estimated for each facies, using the vertical and horizontal variogram models. As an example, the estimation results are illustrated for three facies in Fig. 21.



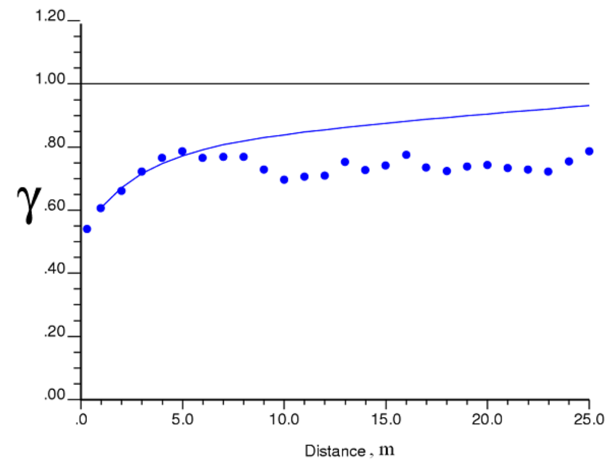
(a) facies 1



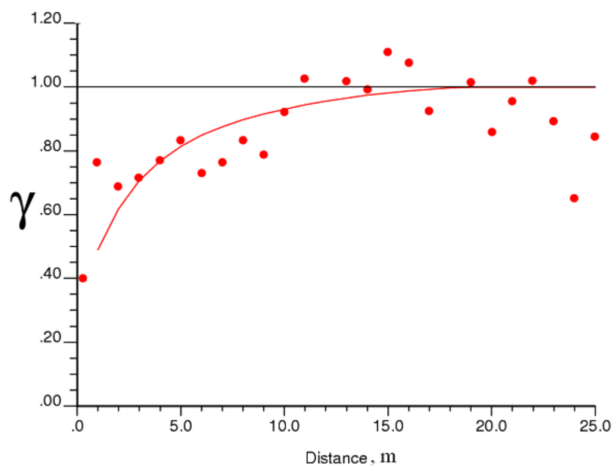
(b) facies 2



(c) facies 3



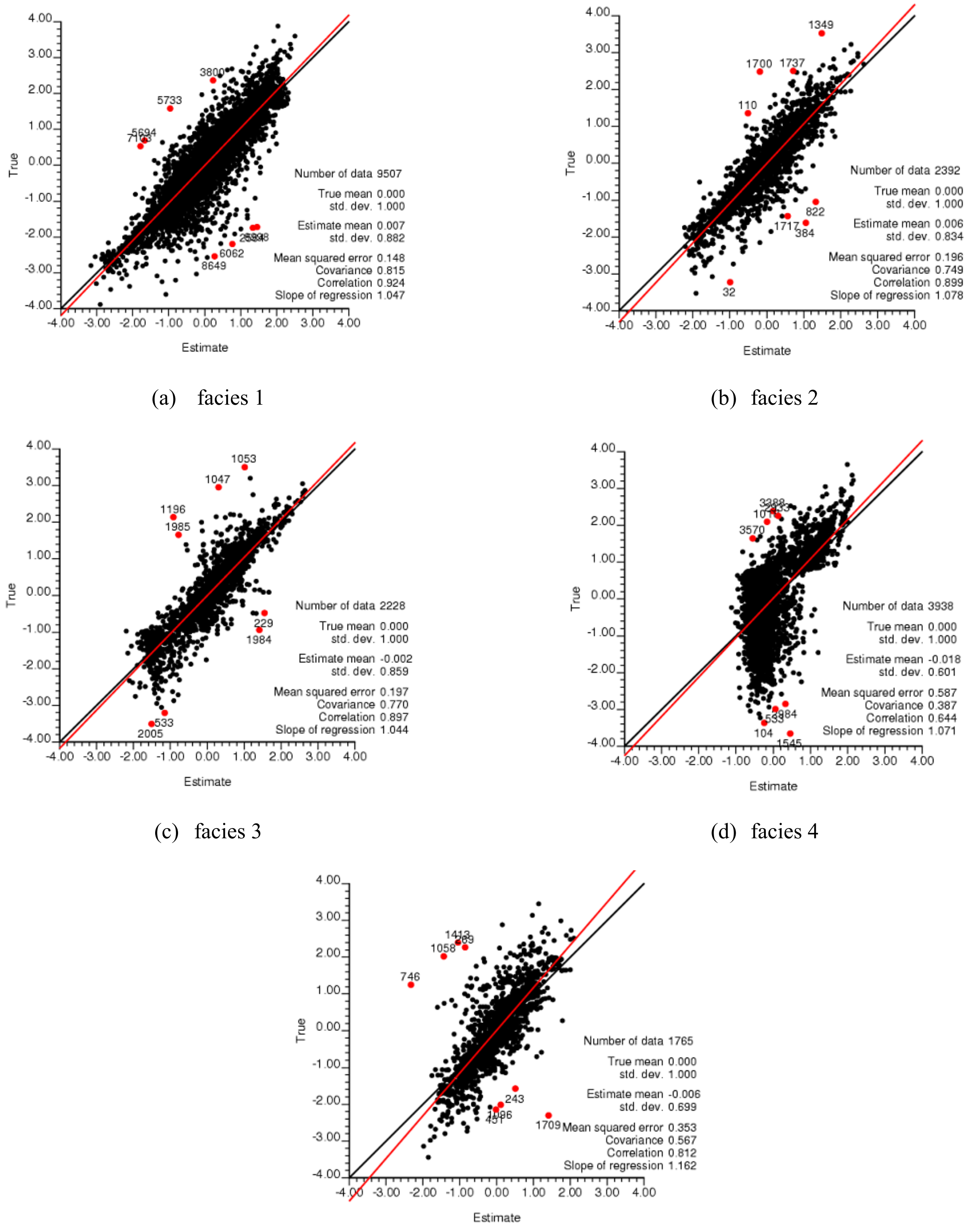
(d) facies 4



(e) facies 5

Fig. 19. Vertical variogram model for porosity of facies

The porosity is then simulated through 100 realizations for each facies. The results of simulated results are then merged together, using the facies simulation result. The averages of simulated values for porosity are illustrated in Fig. 22. In order to take the average, the *POSTSIM* command of *GSLIB* is used.



(a) facies 1

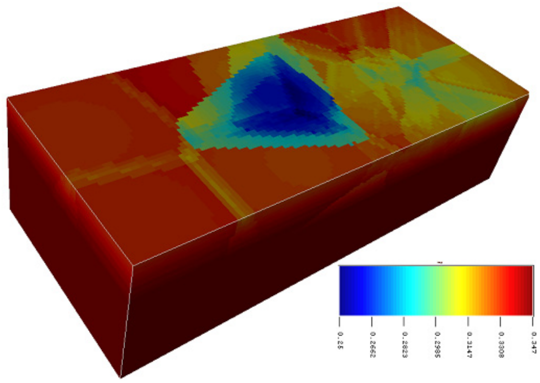
(b) facies 2

(c) facies 3

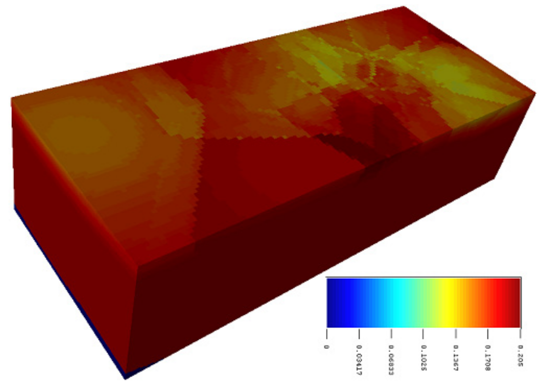
(d) facies 4

(e) facies 5

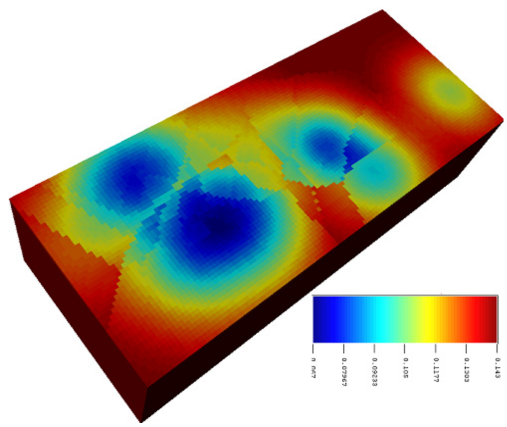
Fig. 20. Cross validation results for porosity in facies



(a) **facies 1**



(b) **facies 2**



(c) facies 3

Fig. 21. Kriging results for porosity in facies

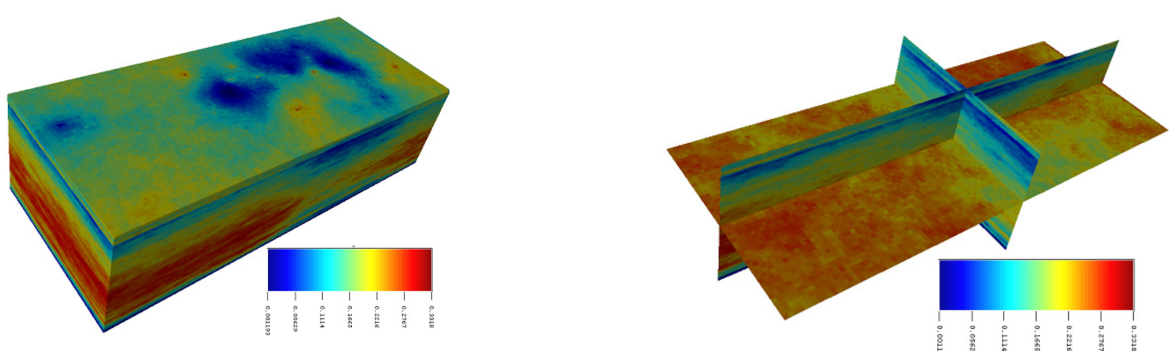


Fig. 22. The simulation results for porosity (merged) range: 0-0.34

4. Conclusion

The prediction of porosity and permeability at unsampled locations of reservoir is one of the important problems in petroleum engineering. The goal of mini modeling is to address the scale changing from the *dm* scale to the scale of flow modeling. In this paper, all steps of mini modeling are explained. The directional permeability of each mini model is calculated with the same basic procedure as the micro models. Each mini model is summarized by an average porosity ϕ, a horizontal permeability K_H, and a vertical permeability K_V. The results form mini models are used directly in geological model construction.

According to the 3D conventional modeling, the porosity of deposit with resolution of dm^3 can be estimated. In this paper full 3D trend is modeled using 2D areal trend and 1D vertical trend. For this method post processing should be done after merging. For this kind of problems, reasonable sensitivity analysis and calibration are required.

5. References

[1] Hong, S. and Deutsch, C. V. (2009). 3D trend modeling by combining lower order trends. Center for Computational Geostatistics, University of Alberta, Edmonton, 130(1-14).

6. Appendix

List of GSLIB sample parameter files that are used in mini modeling and 3D conventional modeling (in alphabetical order)

backtr.par	Parameter file for back transformation to original distribution.
bimodel.par	Parameter file for calculating the bivariate distribution.
blocksis.par	Parameter file for simulating the indicator variables.
cltrans.par	Parameter file for cloud transform simulation.
declus.par	Parameter file for declustering.
flowsim.par	Parameter file for flow simulation.
gamv.par	Parameter file for variogram calculation (irregularly spaced data).
histplt.par	Parameter file for plotting histograms.
kt3d.par	Parameter file for kriging.
merge_multi.par	Parameter file for merging separated columns of data.
mergemod.par	Parameter file for merging the gridded results.
nscore.par	Parameter file for transforming to normal scores.
psctm.par	Parameter file for producing 3D maps.
sgsim.par	Parameter file for generating random numbers.
scatplt.par	Parameter file for plotting the scatter plots.

scatxval.par	Parameter file for cross plotting the results.
scatxval.par	Parameter file for cross plotting the results.
pixelplt.par	Parameter file for plotting 2D results (maps).
postsim.par	Parameter file for averaging the realizations.
vargplt.par	Parameter file for variogram plot.
vmodel.par	Parameter file for variogram modeling.