A PROJECT REPORT ON

APPLICATION OF KRIGING AND STOCHASTIC SIMULATION IN RESERVOIR CHARACTERIZATION

BY

JOHN IDOKO JOB

Student ID: **40462**

MSc. Student, Petroleum Engineering Department, AUST Abuja

Submitted to:

Prof. David O. Ogbe

Head of Petroleum Engineering Department, AUST Abuja

Email: dogbe@aust.edu.ng

Phone: +2348058643856, +2348033792781

April 2017.

Group 1

JOHN IDOKO JOB	40462
TESLIM OLAYIWOLA	40454
OLUWABUNMI SANUSI	40469
MUJEEB ADETAYO	40463
KANNEH LAHAI	40550
CHRISTIAN EZEKWU	40449

ABSTRACT

This report presents the methodology, results obtained, conclusions and recommendations given on a group geostatistical modelling exercise. The Porosity and Thickness hard object data provided for our group (Group 1) is FU_6. To define regional stationarity, a rectangular grid of dimensions 27729ft by 15150ft, containing 100 by 100 grid cells was created and used. The hard objects were analysed using histograms, P-P plots, Q-Q plots and variograms. Variogram models fitting was done by visual inspection and descriptive statistical information were generated for them the hard objects. Descriptions of gross thickness and porosity were generated using ordinary and simple kriging methods.

Three realizations of SGS estimations of porosity values were also done and OOIP was generated for the 100 by 100 grid cells using estimates of thickness and porosity from the Ordinary Kriging estimations. A map of the OOIP was then created and the STOIP calculated for FU_6. For the thickness hard data, Simple Kriging (SK) values range from 0.363ft to 6.2ft while Ordinary Kriging estimates range from 0.094ft to 6.321ft. For the porosity hard data, SK porosity values range from 9.323% in the North-Central topmost regions (or the central parts of the upper regions) to 26.66% in the Central North-Western regions. OK estimates range from 9.131% to 26.66%. The Stock tank oil in place **(STOIP**) in FU_6 was estimated as **24.51901 MMSTB.**

It was observed that Ordinary kriging (OK) presents a better estimation than Simple kriging as it gives a higher representation of the uncertainties/variation. Also, despite high thickness value (4.25ft to 6.2ft), The OOIP map reflects low to moderate hydrocarbon values (204STB to 3049STB) in the North-Central topmost grids/regions. This is as a result of the low porosity values (9.0% to 9.323%) in the region. The Central North-Western regions of FU_6 which possess the highest STOIP values (4010STB to 5985STB) are associated with the highest range of porosity values from the OK estimates (24% to 26.6%). The SGS realizations presented rougher estimates of porosity than the SK and OK maps. SGS, therefore, provides a more representative estimate of the porosity.

INTRODUCTION

CONCEPTS OF RESERVOIR CHARACTERIZATION, KRIGING AND STOCHASTIC SIMULATION

Reservoir Characterization is the description of reservoir properties using all available data (Mohan & Perez, 2002). It is done to provide information to aid decision making regarding field development, asset quantification, etc. Two methods of reservoir characterization are the Conventional method and Improved method or Geostatistics which uses the knowledge of geology and statistics for reservoir characterisation.

Geostatistical methods include Deterministic method: kriging (Simple Kriging, Ordinary kriging) and Stochastic methods such as Gaussian Simulation and Indicator Simulation. Kriging is a basic statistical estimation technique (Jerry L., et al, 1997). It is a procedure for constructing a minimum error variance linear estimate at a location where the true value is unknown. It is an estimation technique/mapping method based on fundamental statistical properties of the data, the mean and the variance (Mohan & Perez, 2002).

According to (Mohan & Perez, 2002), stochastic simulation is a geostatistical method used to generate equally likely descriptions of the reservoir using available qualitative and quantitative data. Stochastic simulation addresses the limitations of Kriging and is seen by experts to be more representative of the true distribution of reservoir properties. The Sequential Gaussian Simulation(SGS) is a pixel-based stochastic simulation technique (D. Ogbe, 2017).

For this work, SGeMS (Stanford Geostatistical Modelling Software) was used. It is a geostatistical modelling software developed at Stanford University that implements several geostatistics algorithms for the modelling of earth systems and more generally space-time distributed phenomena. (Nicolas, Alexandre, & Wu, 2009).

PROJECT OBJECTIVES

- To generate descriptions of gross thickness and porosity using ordinary and simple kriging.
- To compare results from ordinary and simple kriging methods.
- To generate descriptions of porosity for both ordinary kriging and SGS for two to three realizations of the SGS results.
- To use the values from ordinary kriging to generate a map of the original oil in place (OOIP) and to calculate total OOIP.

METHODOLOGY

As earlier mentioned, SGeMS (Stanford Geostatistical Modelling Software) was used for this work. The assigned flow unit is FU_6.

1. DATA PRESENTATION (DEFINING REGIONAL STATIONARITY)

a) Grid Creation

A rectangular grid of dimensions 27729ft by 15150ft, containing 100 by 100 grid cells was created and used. **Grid Parameters** were obtained, from the provided **thickness** hard object (FU6_thickness) as follows:

Min x-cord = -4620ft, Max x-cord = 23100ft; Therefore, Grid width $(\Delta x) = 23100 - (-4620) = 27720ft.$

Also, Min. y-cord = $-4950ft,$ Max. y-cord =10200ft; Therefore, Grid Length $(\Delta y) = 10200 - (-4950)$ =15150$ft.$

So that grid cell dimensions for 100 by 100 grid cells become: $\frac{\Delta x}{100}$ by $\frac{\Delta y}{100} = 277.2ft\ by\ 151.5ft$

Grids were stored as “Group1_grid_thickness” and “Group1_grid_porosity” for the thickness and porosity hard objects respectively.

2. DATA ANALYSIS

Thickness hard object (FU6_thickness) and Porosity hard object (FU6_porosity) were loaded into SGeM and analysed using histograms, P-P plots. Q-Q plots and variograms.

a) Experimental Variogram Creation and Fitting of Variogram Models for Porosity and Thickness Hard Objects.

i. Estimation of **Lag Separation** (for thickness) for 15 number of Lags: According to (Deutsch, 2014), Lag spacing is chosen equal to the data spacing aligned with the direction of the experimental variogram. Also, the variogram should cover about half of the data domain. The lag separation was therefore estimated as:

$$\text{Lag separation} = \frac{\Delta x/_2}{15} = \frac{27720/_2}{15} \approx 900\text{ft}$$

ii. Estimation of **Lag Tolerance** (for thickness): The lag tolerance is typically chosen to be equal to half of the lag spacing (Deutsch, 2014). Therefore, Lag tolerance = $\frac{900}{2} = 450ft$

iii. Estimation of **Bandwidth** (for thickness variogram): Bandwidth has little effect in the variograms results (Deutsch, 2014) and can be left large in most cases.

$$\text{Bandwidth} = \sqrt{(\Delta x)^2 + (\Delta y)^2} = \sqrt{(27720)^2 + (15150)^2} = 23690ft$$

iv. Estimation of **dip tolerance:** azimuth and dip tolerances of 22.5° corresponding to a 45° span, for points being considered, was used. (Deutsch, 2014).

v. **Dip = 0** for horizontal variograms and 90˚ for vertical variograms.

The input parameters for the variogram modelling are shown in Table 1.

TABLE 1: PARAMETERS FOR VARIOGRAM CREATION FOR POROSITY AND THICKNESS HARD OBJECTS

Parameters	Input Value for Thickness Variogram	Input Value for Porosity Variogram
Number of Lags	15	20
Lag separation	900*ft*	1000ft
Lag tolerance	450*ft*	500ft
Number of directions	1	1
Bandwidth	23692*ft*	23690ft
Azimuth	90	90
Dip	0	0
Dip tolerance	22.5˚	22.5˚

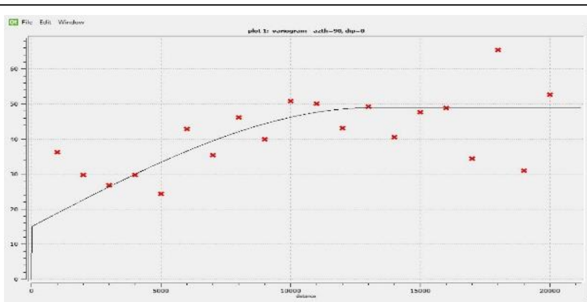

Figure 1: Porosity Variogram Model

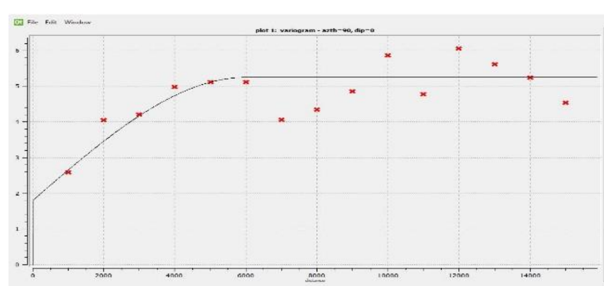

Figure 2: Thickness Variogram Model

b) **Variogram Models Fitting and Estimation of Sill, Nugget and Range.**

These were done by visual inspection. See Figures 1 and 2 above for the variogram experimental and variogram models.

The Variograms were stored as "Experimental_variogram_thickness" and "Experimental_variogram_porosity" for the thickness and porosity variograms respectively.

3. SIMPLE AND ORDINARY KRIGING ESTIMATES OF POROSITY AND THICKNESS FOR FU_6

Descriptions of gross thickness and porosity were generated using ordinary and simple kriging. Table 2 summarises the methodology and parameters used for both OK and SK for thickness and porosity.

TABLE 2: METHODOLOGY AND INPUT PARAMETERS FOR ORDINARY AND SIMPLE KRIGING OF THICKNESS AND POROSITY

METHODOLOGY		**INPUT DATA, PROPERTY OR OBJECT**			
		Ok_Thickness	**OK_Porosity**	**SK_Thickness**	**SK_Porosity**
Loading of hard object		FU6_thickness	FU6_porosity	FU6_thickness	FU6_porosity
Specify existing variogram		Experimental_variogram _thickness	Experimental_variogram _porosity	Experimental_variogram _thickness	Experimental_variogram _porosity
appropriate grid selection		Group1_grid_thickness	Group1_grid_porosity	Group1_grid_thickness	Group1_grid_porosity
Input of range values	Max	12150	13200	12150	13200
	Med	6000	13200	6000	13200
	Min	0	0	0	0
Input of Azimuth		90˚	90˚	90˚	90˚
Input of mean		N/A	N/A	3.01905	0.201603
Saving and running algorithm		Computed for two obtained models and Saved as "OK_Thckness_Nul(1.9)" for model with Nulget of 1.9 and OK_Thckness_Nul(1.8) for the second model with Nulget of 1.8	Computed and Saved as "Ok_porosity_Nu(15)"	Computed for two obtained models and Saved as "SK_Thckness_Nul(1.9)" for model with Nulget of 1.9 and SK_Thckness_Nul(1.8) for the second model with Nulget of 1.8	Computed and Saved as "Sk_porosity_Nu(15)"

4. SEQUENTIAL GAUSSIAN SIMULATION (SGS) DESCRIPTION OF POROSITY FOR FU_6

Three realizations of SGS estimations of porosity values were done as described in Table 3 below.

TABLE 3: METHODOLOGY AND INPUT PARAMETER FOR THE SEQUENTIAL GAUSSIAN SIMULATION OF OK POROSITY

METHODOLOGY	**INPUT PARAMETERS**	
Input of simulation grid name	Group1_grid_porosity	
number of realizations	3	
Kriging type	Ordinary Kriging	
loading of hard data	FU6_porosity	
Loading of the existing variogram model	Ok_porosity_Nu(15)	
	Max	13200

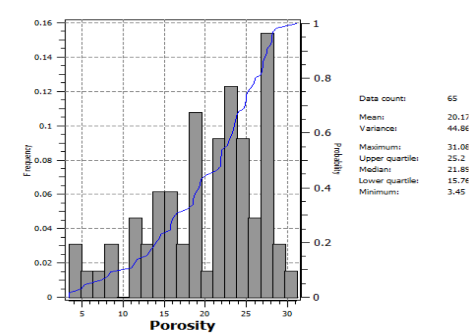

Figure 3: Histograms of Porosity

Range specification	Min	0
Specifying angle (Azimuth)	0	
Saving and running Algorithm	Realization 1	Computed and saved as “SGS_Porosity_OK_real0”
	Realization 2	Computed and saved as “SGS_Porosity_OK_real1”

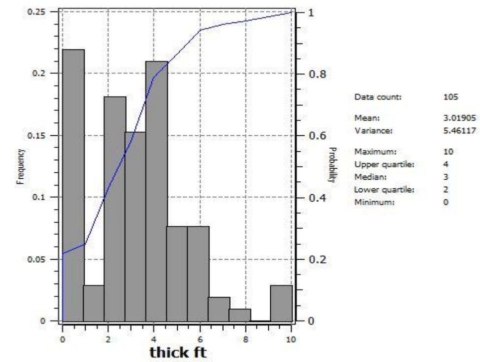

Figure 4: Thickness Hard objects.

5. ESTIMATION OF OIL IN PLACE (OOIP) USING OK ESTIMATES AND MAPPING OF OOIP FOR FU_6

The OOIP was generated for the 100 by 100 grid cells using estimates of thickness and porosity from the Ordinary Kriging estimations and the model below:

$$OOIP\ (STB) = \frac{A \times h \times NTG \times (\frac{\emptyset}{100}) \times (1 - \frac{Sw}{100})}{5.615 \times B_o}$$

$Where:$ Area, A = $\left(\frac{\Delta x}{100}\right) * \left(\frac{\Delta y}{100}\right) = 277.5 * 152 = 42180 ft^2$ for each grid cell; $Sw = 0.2\ (Given)$;

NTG= $0.75\ (Given)$; h= $estimates\ of$ “OK_Thickness(Nu,1.8)” kriging

$\emptyset =\ estimates\ of$ “Ok_porosity_Nu(15)” kriging and $Bo = 1\frac{rb}{STB}\ \ (Given)$

The estimated OOIP values were then imported into SGeMS as a cartesian grid and visualized to create the OOIP map.

RESULTS ANALYSIS AND DISCUSSION

1. **RESULTS OF DATA ANALYSIS**

a) Results of Histograms for Thickness and Porosity Hard Objects

The histograms for thickness and porosity of FU_6 hard objects are shown in Figures 3 and 4 above and the descriptive statistical information is given in Table 5 below.

b) Results of Variogram Analysis for Porosity and Thickness Hard Data.

These are given in Table 4 below and the variograms are shown in Figures 1 and 2 above.

2. **(COMPARISON OF) RESULTS OF SK AND OK KRIGING FOR POROSITY AND THICKNESS FOR FU_6**

The maps of the OK and SK estimates of thickness and porosity are shown in Figures 5 and 6 respectively. Variance maps for them (Figures 7 and 8) show the presence of uncertainties in estimations in regions not well populated in the kriging estimate maps.

For the **Thickness Kriging Estimates,** Simple Kriging (SK) values range from 0.363ft to 6.2ft while Ordinary Kriging estimates range from 0.094ft to 6.321ft. Although both maps are similar with higher thickness values of 4.25ft to 6.2ft in the Central parts of the upper regions (i.e. Northern-central-top most regions) and South Eastern grids, the SK map presents a smoother estimation. This is easily discernible from the variance maps; the SK variance map shows lower variation in thickness, ranging from 2.2ft in the central region to 5.07ft in the South-Western, South Eastern and North

Eastern corners of the map. For the OK variance map, variance range from 2.27ft in the central region to 6.41ft in the South Eastern or lower right corner of the map.

For the **Porosity Kriging Estimates,** the SK and OK maps also do not show significant variations. SK porosity values range from 9.323% in the Northern-central-top most regions (or the central parts of the upper regions) to 26.66% in the Central-North-Western regions. OK estimates range from 9.131% 26.66%. Like the thickness maps, variation in porosity are better displayed by SK than the OK as indicated by their variance maps. The variance readings for porosity are about 18.33% to 45.51% for Simple kriging and 16.33% to 56.11% for OK. Again, the SK estimation technique reflects lower variations in porosity than the OK estimation method.

3. RESULT OF SEQUENTIAL GAUSSIAN SIMULATION (SGS) OF POROSITY FOR FU_6

Descriptions of porosity for FU_6 using SGS for 3 realizations are shown in Figures 13, 14 and 15 respectively.

4. RESULT OF ORIGINAL OIL IN PLACE (OOIP) ESTIMATION AND MAPPING FOR FU_6

The Stock tank oil in place **(STOIP**) in FU_6 was estimated as **24.51901 MMSTB.** The map for OOIP is shown in Figure 16.

CONCLUSIONS

At the course of this project;

- Descriptions of gross thickness and porosity were generated for FU_6 using ordinary and simple kriging.
- Results from the above ordinary and simple kriging estimates were compared and presented.
- Descriptions of porosity were generated for both ordinary kriging and three realizations of Sequential Gaussian Simulation (SGS).
- Values of porosity and thickness from ordinary kriging estimations were used to generate a map of the original oil in place (OOIP) and to calculate total OOIP for FU_6.

OBSERVATIONS

Ordinary kriging(OK) presents a better estimation than Simple kriging as it gives higher representation of the uncertainties/variation. This is attributable to the fact that OK uses the mean value in the estimation, unlike Simple Kriging.

Despite high thickness value (4.25ft to 6.2ft), The OOIP map reflects low to moderate hydrocarbon values (204STB to 3049STB) in the Northern-Central-top most grids/regions. This is as a result of the low porosity values (9.0% t0 9.323%) in the region.

The central, North-Western regions of FU_6 which possess the highest STOIP values (4010STB to 5985STB) are associated with the highest range of porosity values from the OK estimates (24% to 26.6%).

The SGS realizations present rougher estimates of porosity than the SK and OK maps. SGS, therefore, provides a more representative estimate of the porosity.

ADDITIONAL TABLES AND FIGURES

TABLE 4: RESULT OF VARIOGRAM ANALYSIS FOR THICKNESS AND POROSITY HARD OBJECTS

Objects	Fitted Variogram Model(s) Type	Model Variogram(s) Parameters				
		Nugget (ft)	Sill (ft)	Range (ft)		
				Max	Med	Min
Thickness	Spherical	1.8	3.45	12150	6000	0
Porosity	Spherical	15	34	13200	13200	0

TABLE 5: RESULTS OF DESCRIPTIVE STATISTICS FOR HARD OBJECT DATA

Parameter	Porosity (%)	Thickness (ft)
Data count	65	105
Mean	20.1603	3.01905
Variance	44.863	5.46117
Maximum	31.08	10
Upper quartile	25.2	4
Median	21.89	3
Lower Quartile	15.76	2
Minimum	3.45	0

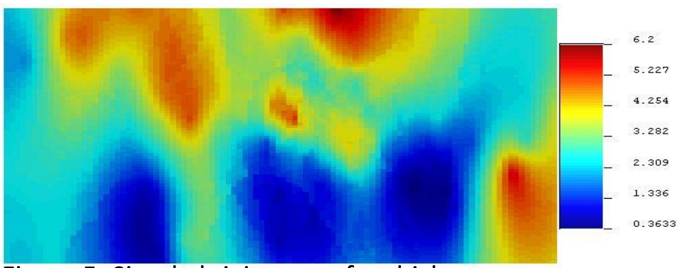

Figure 5: Simple kriging map for thickness

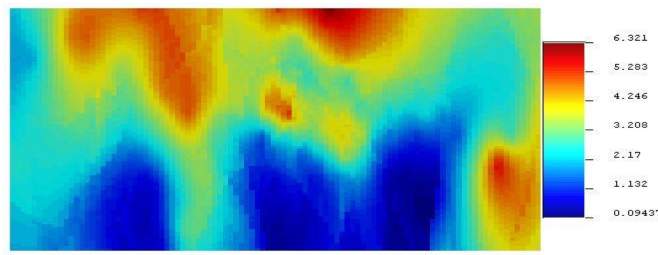

Figure 6: Ordinary kriging map for thickness

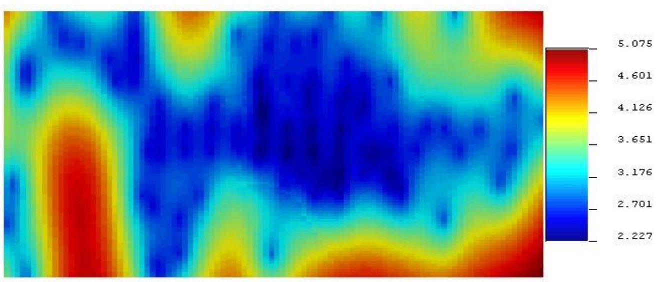

Figure 7: Simple kriging Variance map for thickness

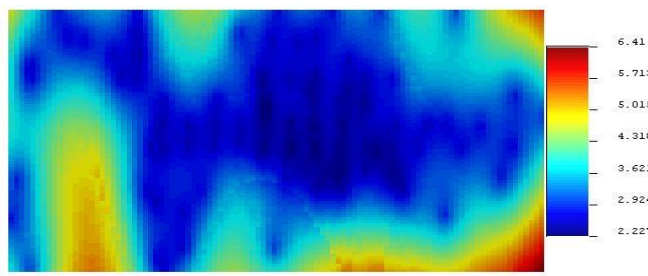

Figure 8: Ordinary kriging Variance map for thickness

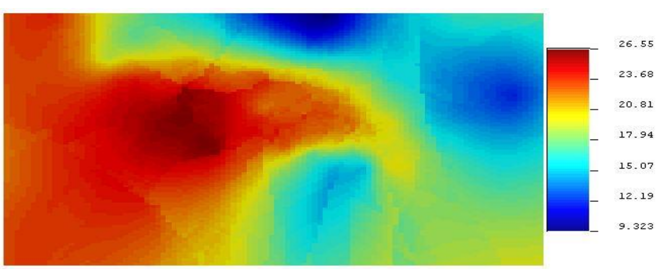

Figure 9: Simple kriging map for porosity

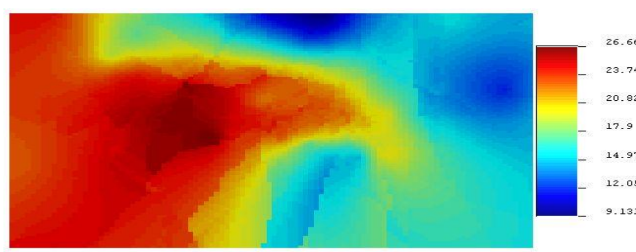

Figure 10: Ordinary kriging map for porosity

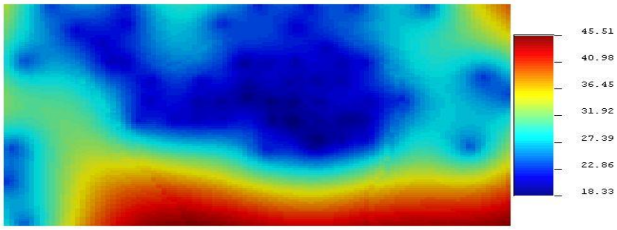

Figure 11: Simple kriging variance map for porosity

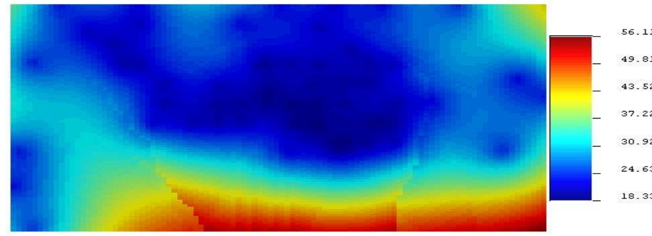

Figure 12: Ordinary kriging variance map for porosity

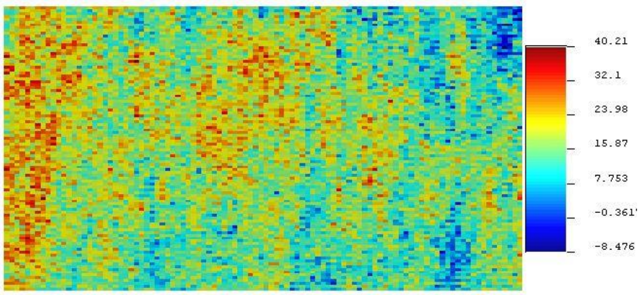

Figure 13: SGS realization 0 map for porosity

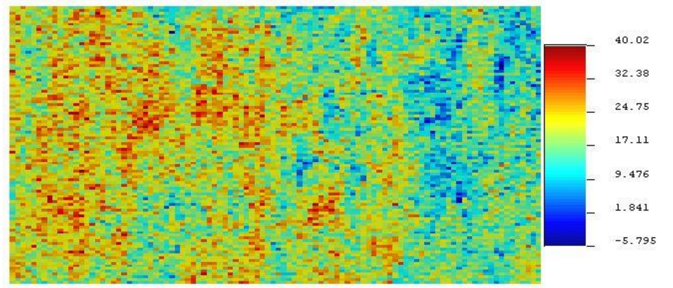

Figure 14: SGS realization 1 map for porosity

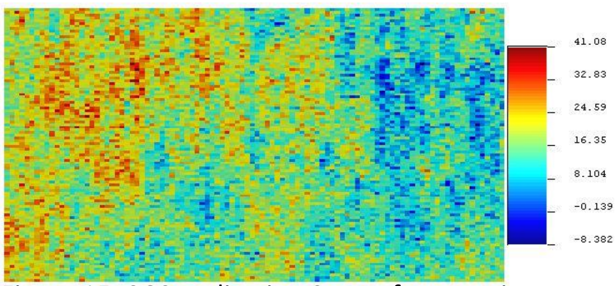

Figure 15: SGS realization 2 map for porosity

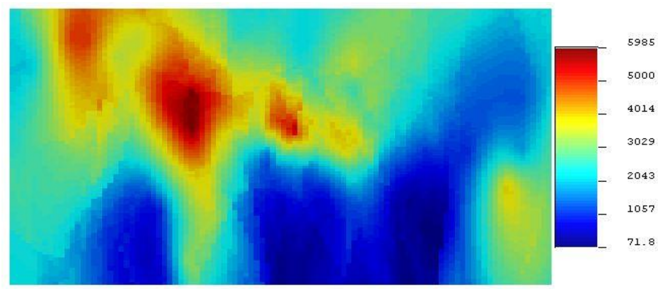

FIGURE 16: OOIP MAP FOR FU_6

REFERENCES

Deutsch, J. (2014). Experimental Variogram Tolerance Parameters. *Geostatistics Lessons*, 1–5. Retrieved from http://www.geostatisticslessons.com/lessons/variogramparameters

Jerry L. J., Larry W., L., Patrick W. M., C., & David J., G. (1997). *Statistics for Petroleum Engineers and Geoscientists*. (L. W. Lake, Ed.). USA: Prentice Hall Petroleum Engineering Series.

Mohan, K., & Perez, G. (2002). *Applied Geostatistics for Reservoir Characterization*. Richardson, Texas: Society of Petroleum Engineers.

Nicolas, R., Alexandre, B., & Wu, J. (2009). *APPLIED GEOSTATISTICS WITH SGeMS - A User's Guide*. *Applied Geostatistics with SGeMS*. Cambridge, UK: Cambridge University Press.

O. Ogbe, D. (2017). Geostatistics for Reservoir Characterization. AUST. Abuja Nigeria.