

2D Geostatistical Modeling and Volume Estimation of an Important Part of Western Onland Oil Field, India

Satyajit Mondal*, Liendon Ziete, and B.S.Bisht (GEOPIC, ONGC)

M.A.Z.Mallik (E&D, Directorate, ONGC)

Email: mondal_satyajit@ongc.co.in

Summary

The purpose of the present study is to carry out geostatistics based 2D reservoir modeling of an important oil field area. Study involves generation of Simple Kriging (SK) and Sequential Gaussian Simulation (SGS) based 2D models of zone thickness, pay thickness, porosity and water saturation. These models show few important areas that helped identifying prospect of new development wells and testing of the existing wells. Finally reservoir volume was calculated from Simple Kriging and SGS based E-type estimation models. This reservoir volume is in agreement with the 3D reserve calculated from Geostatistics based 3D model.

Key Words: Simple Kriging, Sequential Gaussian Simulation, E-type estimation

Introduction

Reservoir Characterization is a method to integrate geological and geophysical data from various sources and generate numerical models based on limited reservoir properties such as lithofacies, thickness, porosity and fluid saturations to predict reservoir flow behavior between wells. The real challenge of reservoir characterization is to integrate all the data into a reservoir model, which will be able to handle the uncertainty involved in reservoir description (Holden et al., 1992).

Geostatistics based 2D modeling of a reservoir is an important and easy method of characterizing a reservoir and same has been attempted here for an important pay in an important part of western onland oil field, India. All of the Statistical and Geostatistical calculations and graphical output was generated using SGeMS and WinGslib Software systems.

Geostatistical Concepts

Variogram

Variogram is the most widely used geostatistical technique for describing the spatial relationship. The

Geostatistical modeling starts with computing and modeling semi-variogram and then estimating the desired variable in unsampled location. In mathematical form, the semi-variogram is defined as:

$$\gamma(\vec{L}) = \frac{1}{2} V[X(\vec{u}) - X(\vec{u} + \vec{L})]$$

It is half of the variance of the difference between the two values located \vec{L} distance apart.

The variogram (for lag distance L) is defined as the average squared difference of pairs, separated approximately by L. Mathematically, it is defined as

$$\gamma(\vec{L}) = \frac{1}{2n(\vec{L})} \sum_{i=1}^{n(\vec{L})} [X(\vec{u}_i) - X(\vec{u}_i + \vec{L})]^2$$

where $n(\vec{L})$ = number of pairs at lag distance \vec{L} ;

$X(\vec{u}_i)$ and $X(\vec{u}_i + \vec{L})$ = data values for the i th pair located \vec{L} lag distance apart.

and $\gamma(\vec{L})$ is estimated value based on sample data

Final goal of variogram modeling is to determine sill, range and nugget effect by fitting experimental variogram with common models such as: exponential, spherical and gaussian etc. This variogram model acts as input in the estimation process.

Kriging

Kriging is a family of generalized linear regression technique (Davis, 2002) in which the value of property at unsampled location is estimated from value at neighboring locations based on spatial statistical model which is popularly known as variogram that represents the internal spatial structure of the data. The value at unsampled location is estimated by

$$X^*(\vec{u}_0) = \sum_{i=1}^n \lambda_i X(\vec{u}_i)$$

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where $X(\vec{u}_i)$ and λ_i represents the value of the sample and weighting factor at point i , respectively. $X^*(\vec{u}_0)$ is the kriging estimator.

The goal of an estimation procedure is to calculate weights assigned to individual neighboring points. The value of weights depends on the spatial relationship between the unsampled location and neighboring points as well as the relationship among neighboring values. These relationships are obtained from variogram modeling (Kelkar, 2002).

Sequential Conditional Simulation

Sequential conditional simulation methods are kriging based methods where all unsampled locations are sequentially visited in random order until all unsampled points are visited and value of the desired variable is simulated in unsampled location based on estimate, as well as local uncertainty (Kelkar, 2002). Sequential Conditional Simulation generates multiple realisations through the order in which unsampled locations are visited as well as the way in which a value is sampled (simulated) at the unsampled location. Two Sequential simulation methods used for categorical and continuous variables are sequential indicator simulation(SIS) and sequential gaussian simulation (SGS) respectively. These methods are executed by the following steps

1. Transform the original data into new domain
2. Modeling variograms in transformed domain
4. Determine a randomly selected path to visit all the unsampled locations
5. Sequentially estimate values at the unsampled locations with kriging based techniques. The conditioning data consists of all original data and all previously simulated values found within a neighborhood of the location being simulated.
6. Backtransform the values to the original domain.

Methodology

For this study, we considered input of 171 wells in 2D space. The basic work flow involves building model database in spreadsheet format and exporting the same in SGeMS (Remy et al. 2009) . In this work

four variables viz. Zone thickness, Pay thickness, Porosity and Water Saturation were analyzed. The basic workflow used herein for the 2D modeling is illustrated in Figure 1.

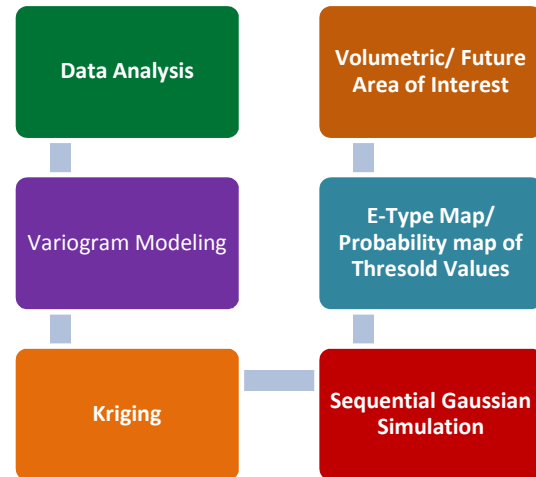


Figure 1: Workflow of 2D Geostatistical Modeling

2D Geostatistical Modeling

a) Zone Thickness

For zone thickness modeling, we used 171 data points. Data analysis work starts with posting of zone thickness values (Figure 2) and data analysis.

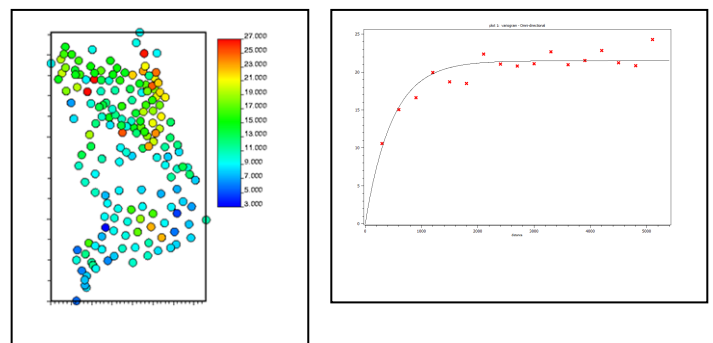


Figure 2: a) Posting of Zone Thickness b) Omni-directional model variogram for zone thickness. The model chosen is exponential with sill=21.5 and Ranges of 1440m, 1080 m and 630 in Max, Med and Min axis direction.

For variogram modeling of zone thickness, we used 17 lags with lag separation and lag tolerance of 300 m each. The experimental and model variogram for

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omnidirection is given in Figure-2b. This exponential variogram model was used to make Simple kriging based 2D model which is shown in Figure 3.

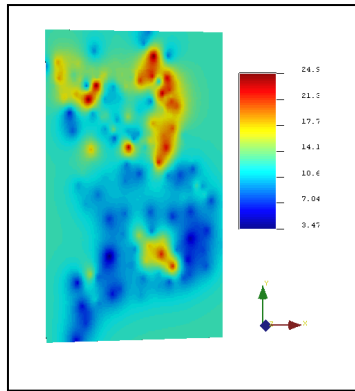


Figure 3 : Simple Kriging estimation of zone thickness

SGS based Zone Thickness map

SGS uses a normal score transformation to turn zone thickness values at wells into values that perfectly follow a normal distribution (i.e Mean=0 and Std.=1) and will then populate these values into grids based on criteria of Kriging technique and search area. Therefore Zone thickness require a normal score transformation and variogram analysis for the transformed data and same is used as input in SGS. Finally simulated grid values are backtransformed according to the histogram of the target variable. The original and transformed Zone thickness histogram are shown Figure-4a and Figure- 4b respectively.

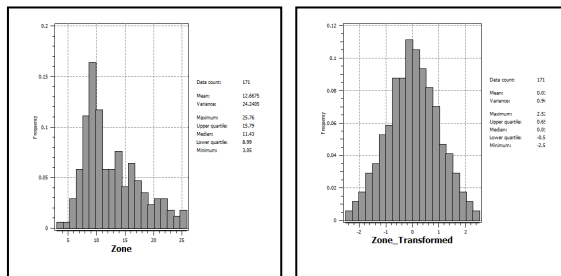


Figure 4 : Histogram showing data distribution of a) True zone thickness b) Transformed zone thickness

SGS based zone thickness map was generated with variogram input and applying Simple Kriging Method. Two hundreds realizations were generated

and E-type estimation of the zone thickness map is given in Figure 5.

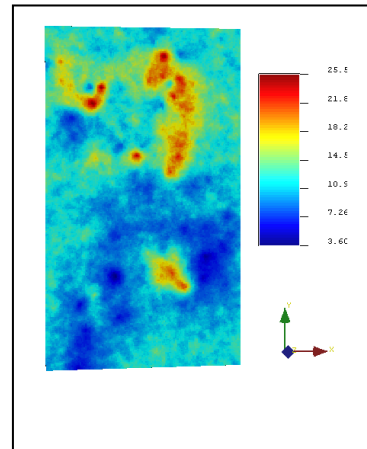


Figure 5 : E-Type estimation of Zone thickness

b) Pay Thickness

The pay thickness of the reservoir in 171 wells were finalized based on available well records, processed logs and well performance. Simple Kriging based 2D model was generated from effective pay in 171 wells. Finally two hundred realizations were generated based on SGS method and E-type estimation is shown in Figure 6a. Probability map of pay thickness above 5 m is shown in Figure 6b. These two maps show 6 distinct areas with good effective pay thickness ranging from 5 m to 12 m.

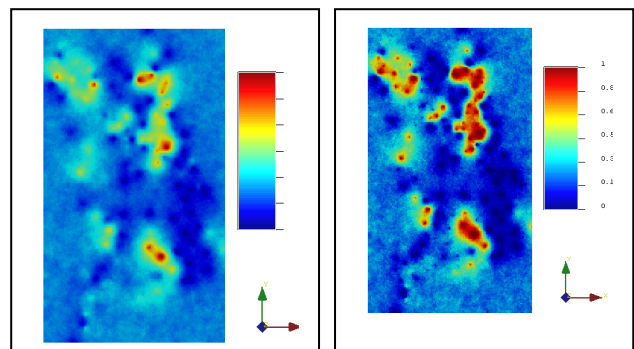


Figure 6: a) E-Type estimation of Pay thickness b) Probability map for pay thickness above 5 m

c) Porosity

Porosity values in 89 locations were the basic input for 2D Geostatistical modeling of porosity and same is posted in Figure 7a. The E-type estimation of

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porosity from SGS method is shown in Figure 7b. Figure 8a to Figure 8d represents Probability of porosity value above 30%, 25%, 19% and 10% respectively. It is evident from Figure 7 and Figure 8 that there exists four distinct regions of good porosity. Among them, two are in the north, one in west and one in south.

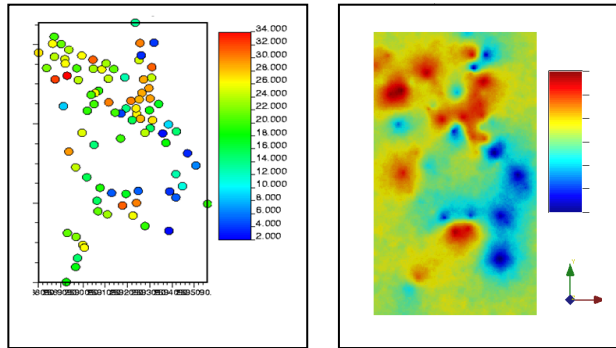


Figure 7: a) Location map of porosity b) E-Type estimation of Porosity

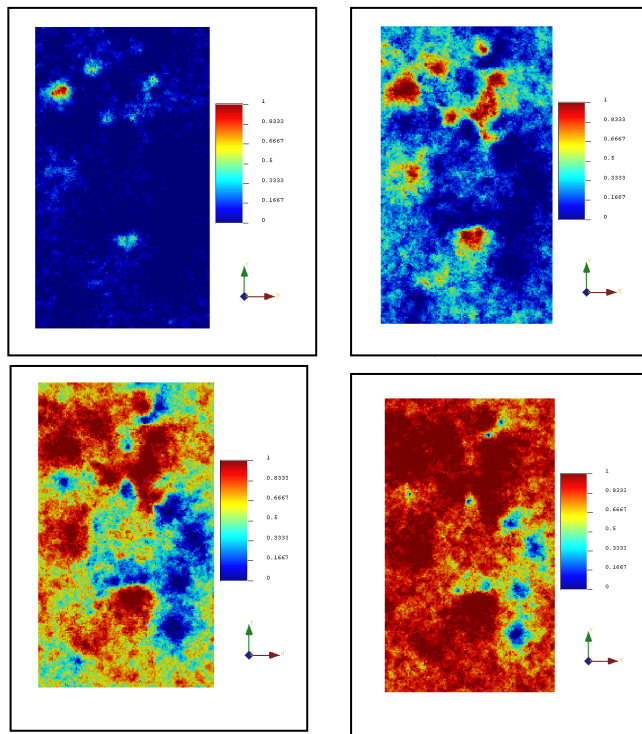


Figure 8 : Probability that Porosity above a) 30% b) 25%, C) 19%, and d)10%

d) Water Saturation

Water Saturation (Sw) modeling was done based on input of 93 Sw data points in 2D space. Location map of Sw is given in Figure 9a. First Saturation modeling

was done by variogram based simple kriging method. To capture uncertainty, we used SGS method and generated 200 realizations of Sw. Figure 9b shows E-Type estimation of Sw.

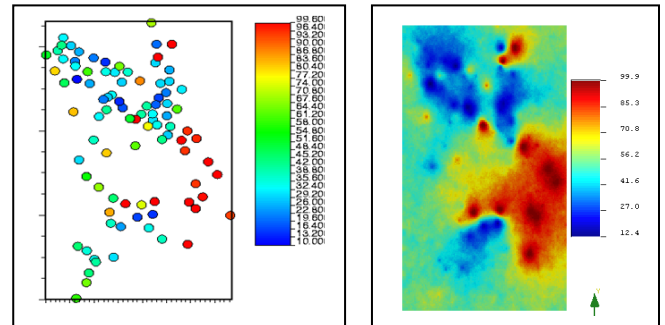


Figure 9: a) Location map of Sw b) E-Type estimation of Sw

Probability of Sw below 30%, and 50% respectively are shown in Figure 10a to Figure 10b. Figure 9b and Figure 10 show three distinct regions with low Sw and a definite high Sw area in east.

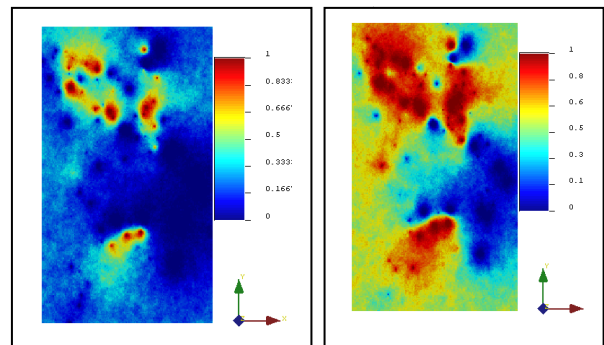


Figure 10 : Probability that Sw below a)30% and b) 50%

Discussions & Recommendations

a) Volume Estimation

Actual area of the study is shown in Figure 11 which is an irregular area that require irregular grid for volume calculation. For this study we exported all the grid data with xy coordinates in spreadsheet and identified grids inside the area of interest and same has been considered for volume calculation. OOIP was also calculated for Porosity cutoff of 8% and Sw cutoff of 80%. Table 1 shows the volume calculated from simple kriging , SGS based 2D model and 3D model.

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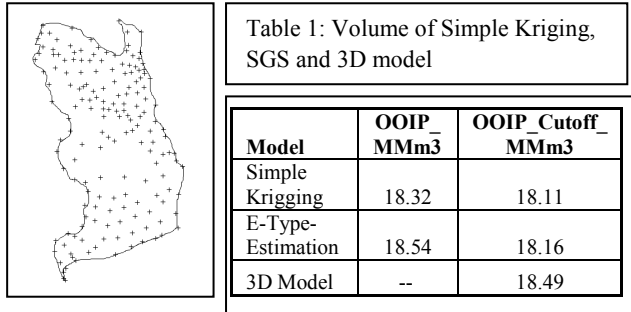


Figure 11: Polygon boundary for which volume was calculated

The OOIP calculated from 3D model is 18.49 MMm3 which matches well with OOIP calculated based on 2D model.

b) Testing of Pay in Well-A, B and C

A close look into 2D models of pay thickness, porosity and water saturation as well as production history of model wells, we suggest to test the pay in wells A, B and C. Based on the testing result, possibility of zone transfer may be considered in future.

c) Development Locations near Well X & Y :

In this part, we observed a well X situated in the NW part of the area was tested positive and produced small amount before converting it into water injector. This area is characterized by good porosity and oil saturation. Therefore we propose for a development location to 300 m NW of Well X. In another case, there is another well Y in the northern part of the model which has already produced good amount of oil and surrounded by area with moderate thickness, porosity and oil saturation. Therefore we also suggest a development location to the 300 m NE of well Y. Figure 13, 14 and 15 show location of X and Y and surrounding areas on pay thickness, porosity and Water saturation map.

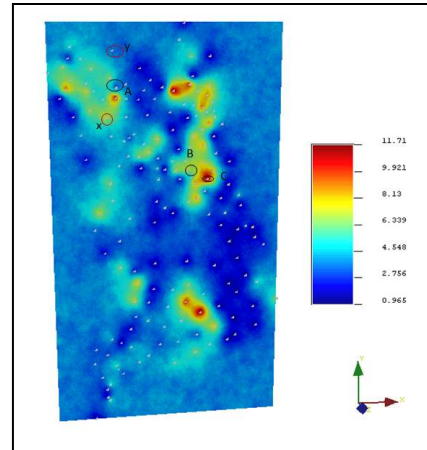


Figure 13 : Well X, Y, A, B and C on Pay Thickness map

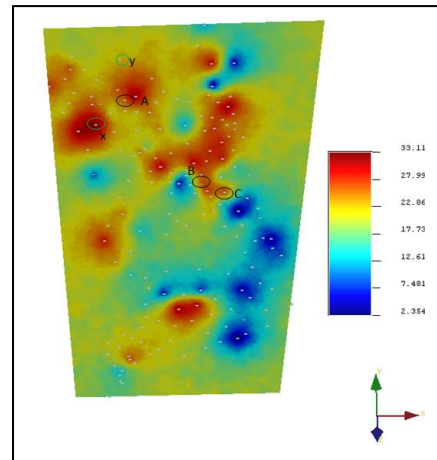


Figure 14: Well X, Y, A, B and C on Porosity map

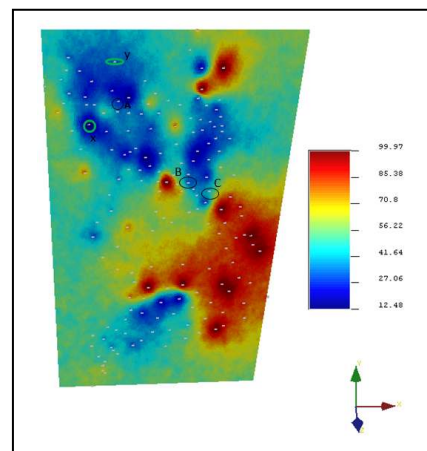


Figure 15 : Well X and Y on Sw map

d) Area of Poor Reservoir Quality

In the Eastern side of the model there is a large area with high water saturation, low porosity and low pay thickness. In this part around 29 wells have been drilled. Among them 19 wells have been drilled with a primary target of pay studied in this work. All these 19 wells are poor producer due to poor reservoir quality. Therefore any future development for the present pay in this area must be done cautiously.

Conclusions

2D Geostatistical modeling is an effective tool for quick-look study to characterize a reservoir. Another advantage of 2D modeling is that it allows data posting in 2D space which helps to visualize the variation of reservoir properties easily. The variogram based geostatistical map generated in this work identifies areas of interest very quickly and effectively. It also shows area with poor reservoir quality.

The data used in this work was generated after an in depth analysis of the available processed logs, well cards and well performance which helped to get a 2D reserve that is in agreement with the reserve calculated in 3D model.

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The views expressed in this paper are solely of the authors and do not necessarily reflect the view of ONGC.