# Generation of regional trend from Boolean log of lithofacies for building a realistic fine scale geological model using stochastic facies modelling– A case study

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**Abstract:**
A facies is a distinctive rock unit that forms under certain conditions of sedimentation, reflecting a particular process or environment. To depict the geological process both during and after deposition facies identification and its modelling in 3D space play a vital role in 3D reservoir model. Identification of different reservoir facies and defining its connectivity along with variation of reservoir property is the basic need of geo-modelling process. To address this, delineation of different facies required detailed core analysis, sedimentological studies and in-depth petrophysical analysis. After ascertaining the identification of different facies at well locations their mapping with connectivity in 3D space is required. The facies is defined as numerical values, therefore, data analysis in the geological context and its spatial relationship become essential to reach some logical conclusion.

The objective of the study is to build a fine scale static model which can explain the heterogeneous behaviour and connectivity of the reservoir keeping in view of the geological aspect. An integrated approach was adopted, where log, seismic data interpretation and geological information are translated into reservoir description. Present study pertains to Kalol field western onshore basin of India with complex lithological environments having multiple pay sand inter-bedded with thick coal layers. The study demonstrates methodology and work flow through a judicious combination of precise petrophysical evaluation to build a trend maps from Booleans log, generated from the facies logs. These trend maps in connection with vertical proportion of facies distribution will guide geostatistical tools leading to facies and reservoir property population in 3D space for robust Geo Cellular Model building resulting better field development and hydrocarbon exploitation from this brown field.

Kriging and stochastic methods are widely used in the industry. Kriging is a deterministic interpolation technique giving one best local smooth estimate with the limitation that in a large model low value trends are over estimated and high value trends are underestimated. Stochastic simulation methods are better for capturing the extreme value variation of subsurface by assessing its spatial variability. Schostastic Simulation reproduces histogram and honours spatial variability through variogram. This technique has been applied in this field to build a realistic model which is validated at different well locations. This model is appropriate for flow simulation and allows an assessment of uncertainty with multiple realizations.

**Introduction:**
Present study deals with identification of reservoir facies and their connectivity in heterogeneous reservoirs pertaining to clastic regime of a giant onland oil and gas field of India (Fig-1) with the help of spatial trend map and vertical proportion curve. In the study area the seismic 3D data is of average quality and picking up geological bodies and its architecture has become difficult due to presence of multi layers of coal seams. Low impedance contrast between sand-shale which is inter-bedded with coal, hinders proper imaging of reservoir geometry. Therefore uses of seismic derived attributes are not helpful to delineate reservoir and non-reservoir facies. Spectral decomposition process has been applied to delineate geobodies but any significant observations couldn't be seen (Fig-1A).
Once the facies log is created, a Booleans log has been generated at well locations to understand the trend of the reservoir facies in the area. As the reservoir has limited spatial distribution across the field and use of only geo statistical methods to populate the lithofacies will not give the correct distribution, therefore Geostatistical methods guided by regional trend maps is used to propagate the reservoir facies and Petrophysical property in proper place and direction.
Sequential Indicator Simulation (SIS) with trend was used to propagate the facies in the area. After the facies were populated, Effective Porosity ($\Phi$), Water saturation ($S_w$) & Permeability ($k$) are assigned to the facies in the entire 3D volume through Sequential Gaussian Simulation (SGS). These methods with trend maps has not only given the reservoir distribution pattern but also gives a fair indication of the quality of reservoir which can be expected in yet to be explored/developed areas.

**Understanding of study area:**
Kalol Field falls in the Ahmedabad-Mehsana tectonic block of Cambay Basin. It is located about 16Km north of Ahmedabad city covering an area of around 450 sq. km. There are 11 pay sands i.e. K-II to K-XII from top to bottom sequence occurring between depth of 1250 to 1550m. in the present study an attempt has been made to delineate the spatial distribution in 3D space of K-XII pay, which is limited to the NW part of the study area as shown in Fig-2. The sand quality of this reservoir is having good porosity and permeability.

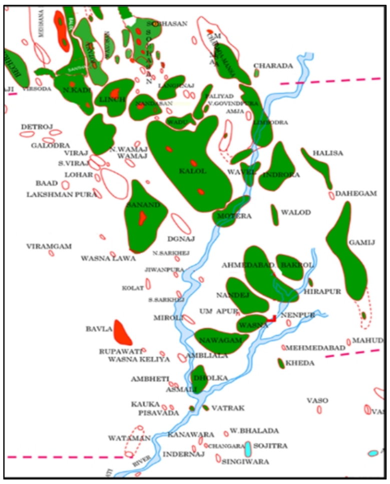

Fig-1: Location map of the study area

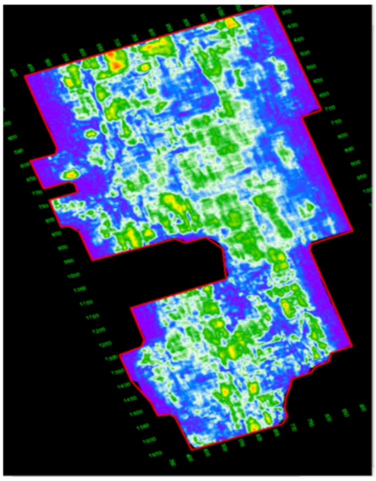

Fig-1A: SD slice at 38 Hz in zone of interest

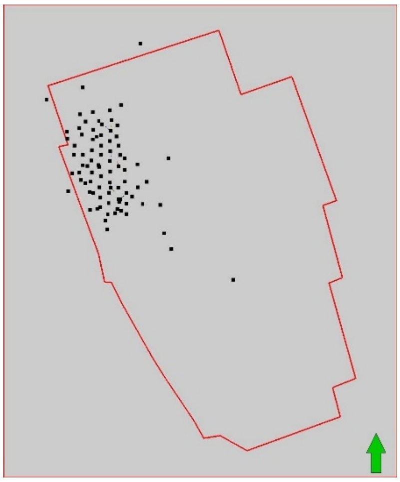

Fig-2: Base Map showing distribution of well having K-XII sand

**Workflow:**

Understanding of geological processes during and after deposition play a crucial role in defining the reservoir connectivity in 3D reservoir model. The identification of reservoir bodies become easier if some seismic attribute respond for it within the limitation of seismic resolution. (Fig-1A). In the absence of 3D seismic data, identification of trend of strata becomes difficult. In the channel type of environment where the orientation/trend of the object is not known all the Geostatistical methods populate the reservoir property in entire 3D space based upon Variogram, VPC using SGS/SGI methods. In this process the reservoir property data are taken from well locations. If the data points are insufficient the prediction of property in unknown area mislead due to stochastic nature of algorithm.

To overcome this situation, from the available log data a regional trend of the reservoir facies using Boolean log may be derived. These trends can be used to bias the distribution of facies within simulation/reservoir grid of a region. Lateral variability and facies transition within the reservoir can be handled with these trends. An attempt has been made to generate a trend map based on facies analysis and has been applied in the area where the reservoir is limited to a certain location.

**Generation of Facies spatial trend:**

From the interpreted Lithofacies logs, Individual and separate facies logs were calculated thus separating each of the facies into separate logs define in terms of 0 and 1 which represents the occurrence of sand facies thus the log created is a Boolean log (Fig-3). These Boolean logs will represent the probability trend maps for different facies. These trend maps restricted the spatial distribution of each log facies spread along the area where the input well data was present as shown in Fig-4. The figure shows that the boolean log are derived from intrepreted facies log having code 1 & 0 for reesrvoir and non-reervoir facies espectively. Porosity and saturation of the respective facies is given in adjacent log tracks.

**Vertical Proportion Curve:**

Vertical proportional curve depict the vertical distribution of all the facies in all the layers in a particular zone. This distribution helps to propagate the facies in vertical direction along with the probability function. The trend map were used in association with Vertical proportion curve in which volume fraction for facies will be a constant value within each horizontal layer of the grid, but will vary vertically according to the specified trend function. With this combination the

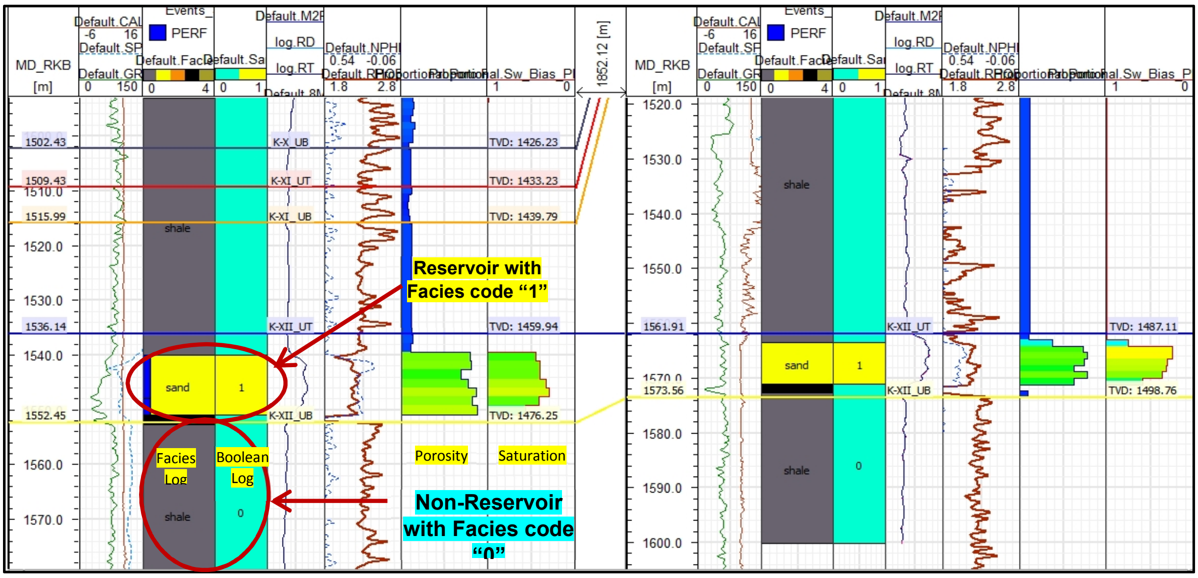


Fig-3: Generation of Boolean log from facies log having facies code 1 & 0 for reservoir and non-reservoir respectively volume fraction steering for each facies will steer towards a volume fraction defined by Vertical Proportion Curve as shown in Fig-5.

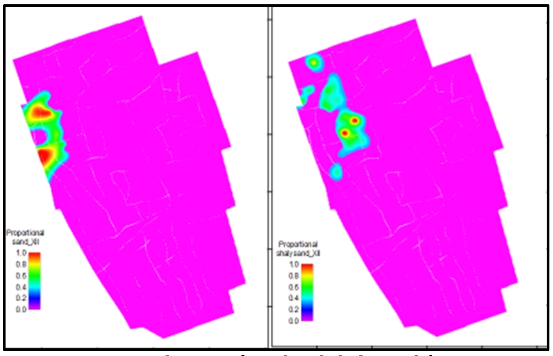

Fig-4: Trend maps of sand and shaly sand facies

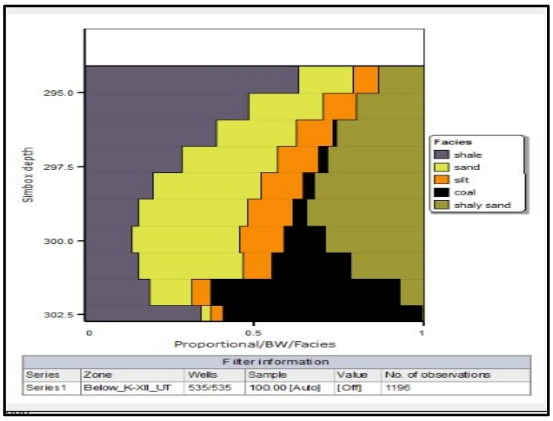


Fig-5: Vertical proportion curve showing facies distribution in vertical direction

**Up scaling of facies:**

Upscaling is a process of assigning a single value to the cell in a 3D grid passing though the well location. Since a facies is discrete log the averaging method "most of" will be suitable for upscaling. In this method the majority of same type of sample will be assigned to that particular grid cell as shown in Fig-6.

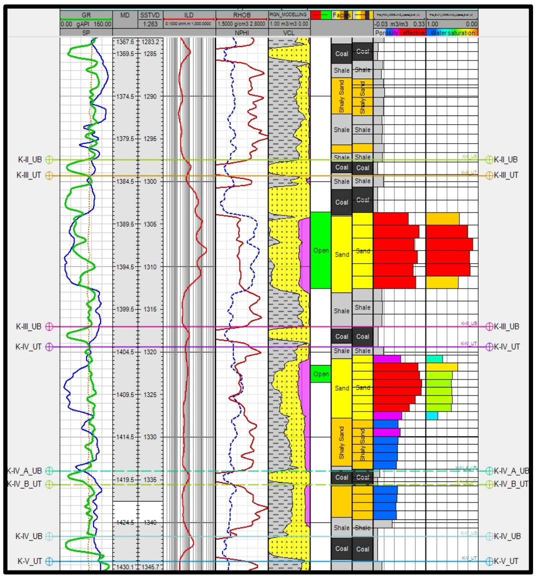

Fig-6: Upscaling of facies log

**Basic Theory:**

**A. Principles of stochastic modeling:**

In general, conditional simulation requires that the basic input parameters—the spatial model (variogram) and the distribution of sample values (cumulative distribution function, or CDF)—remain constant within a given geologic interval and/or facies, from realization to realization. Typically, the structural and stratigraphic model (major structural surfaces and the discretized layers between them) remains fixed. Because each realization begins with a different, random seed number, each has a unique "random walk," or navigational path through the 3D volume. The random walk provides the simulation algorithm with the order of cells to be simulated, and is different from realization to realization; therefore, the results are different at unsampled locations, producing local changes in the distribution of facies and Petrophysical properties in the interwell space. Note that selection of the same random seed always will reproduce the same random walk. This characteristic is for computational convenience. In practice, multiple realizations are performed at or close to the geologic scale, and not necessarily at the flow-simulation scale.

There are two basic categories of conditional simulation methods:

- Pixel-based methods operate on one pixel at a time. They can be used with either continuous or categorical data.
- Object-based methods operate on groups of pixels that are connected and arranged to represent genetic shapes of geologic features. They are used only with categorical data.

**B. Stochastic simulation methods:**

There are several theoretically sound and practically tested conditional-simulation approaches and choosing one can be bewildering and daunting for a novice to stochastic methods. Parametric-simulation techniques assume that the data have a Gaussian distribution, so that a transform of the data typically is prerequisite. Note that indicator data do not undergo such a transform. Furthermore, data transformations are not required in the object-based method, where only indicator data are required. The steps of parametric simulation are:

- Normal-score data transformation
- Computation of variogram biased to facies along vertical, major and minor direction.
- Run the modelling using Sequential Gaussian Simulation with multi-realizations for each facies code.
- Selection of most suitable equal probable realization through testing at blind wells, which are not considered during modelling process.

**C. Sequential simulation:**

- Sequential indicator simulation (SIS) simulates discrete variables, to create equal probable realization of facies (having various facies codes)
- Sequential Gaussian simulation (SGS), simulates continuous variables, such as petrophysical properties e.g. Porosity, water saturation conditioned to facies propagation.

The general sequential simulation workflow can be formulated as:

1. A normal-score transformation of upscaled logs of the facies and petrophysical properties.

2. Randomly selection of a node that is not yet simulated in the grid.
3. Estimation of the local conditional probability distribution function (LCDF) for the residuals at the selected node. The residuals can be calculated by subtracting the grid of an unconditional simulation from a kriged grid of the unconditional values sampled at the geographic coordinates of the wells.
4. Creation of a newly simulated value by adding together the randomly drawn residual value and the mean of the transformed data.
5. Inclusion of the newly simulated value in the set of conditioning data, within a specified radius of the new target location. This ensures that closely spaced values have the correct short-scale correlation.
6. Multi-level iterative processes until all grid nodes have a simulated value.

**Stochastic facies modeling:**

Sequential Indicator Simulation method was used and the upscaled facies were populated using lateral trend maps and vertical proportion curve. The sequential simulation works by visiting each point on the grid to be simulated, calculating the conditional distribution at that point and sampling from that distribution. The conditional distribution is the probability distribution for the facies at the point, given knowledge of the facies at nearby well locations and of previously simulated points nearby. By ‘nearby’ which mean within the search neighborhood of the point to be simulated. The conditional distribution is found approximately using a kriging approach, with the exact methodology depending on the type of simulation that is being applied. With these trend setting as input to the model, indicator variogram model for each facies were also specified. The idea of sequential simulation is to use previously kriged/simulated values as data reproduces the covariance between all of the simulated values.

A variogram is a mathematical tool used to quantify the spatial continuity of a variable. Variogram estimation and definition involves looking at the well observations, and investigating their similarity as a function of the distance between the data points. In general, the similarity between two observations depends on the distance between them. That is, the variability increases with increasing separation distance between two observations. This variability is quantified by calculating the Variance of the increment. For each separation distance, the variance is the sum of the squared difference between all the pairs of observations with that separation distance, divided by the number of observations. Semivariance is generally defined by the equation:

$$\pm(h) = \frac{1}{2}\frac{1}{n(h)}\sum_{i=1}^{n(h)}(Z(x_i+h)-Z(x_i))^2$$

Where z is a datum at a particular location, h is the distance between ordered data, and n (h) is the number of paired data at a distance of h. The semi variance is half the variance of the increments,

$Z(x_i+h)-Z(x_i)$, but the whole variance of z-values at given separation distance h (Bachmaier and Backus, 2008).

The indicator variogram parameters indicate to what degree the facies values in one position are related to the facies values in a position nearby, as a function of their separation distance. This means that they provide information on the confidence with which the value of a cell can be estimated, based on its distance from a cell of known or calculated value.

Variograms were generated for each of the facies.Prediction of facies was checked against the blind wells and found satisfacory (Fig-7A & 7B).

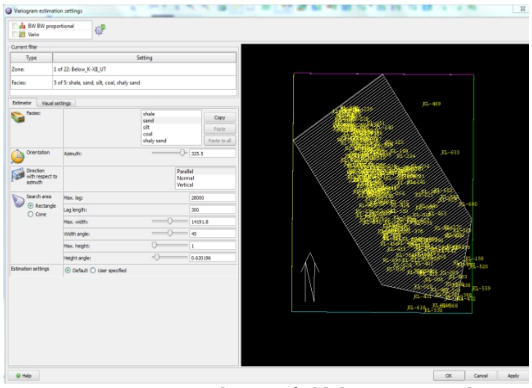

Fig-7A: Variogram showing field deposition trend

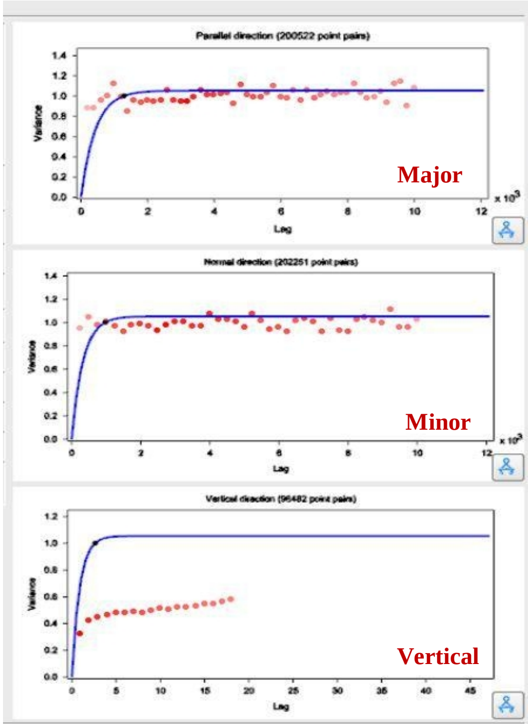


Fig-7B: Directional variogram showing the range of vertical and spatial distribution

Based on these variograms, VPC and trend maps facies has been populated in the entire zone of particular sand which is limited to a particular area of the field. The distribution matches with the wells which were not taken in facies modelling process. Fig-8A and B shows a comparison of the distribution of a facies without and with trend maps. In Fig-8a the sand facies is available in the entire zone of the field because of stochastic nature of the algorithm while fig-8b depict the correct picture as observed in the well drilled in the area shown in green color.

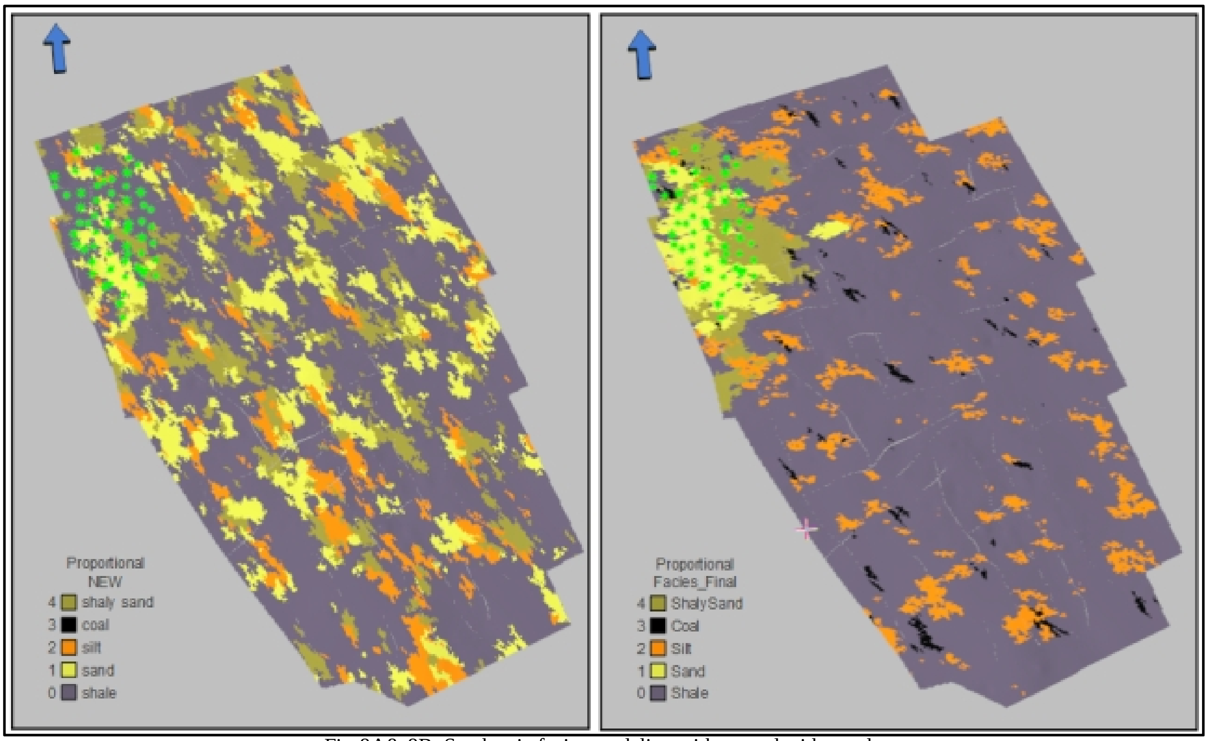

Fig-8A& 8B: Stochastic facies modeling without and with trend maps

**Property modeling:**
Based on this facies model the property modelling has been done for porosity and saturation model biased to the facies in this field.

**Porosity Modeling:** The upscaled porosity logs were used in the Porosity Modeling. Using SGS technique porosity derived from upscaled logs were propagated biased to facies. The samples from petrophysical parameters were transformed to a Gaussian (normal) distribution (Fig-9A & B) by the application of certain geological and statistical transformations.

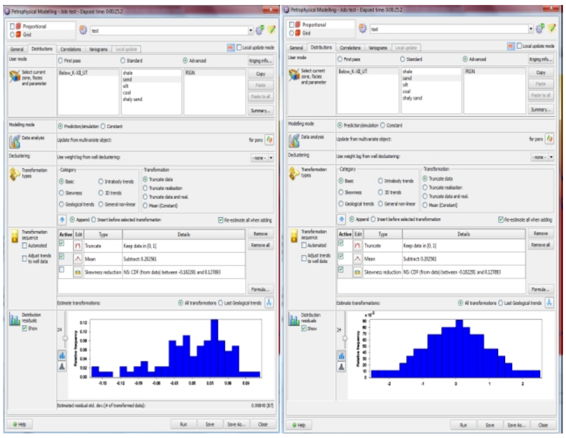
Fig-9A& 9B: Normal and Gaussian distribution of petrophysical property (porosity) for SGS.

Variograms for porosity were generated for each facies code in the zone and prediction of the property was checked against the blind wells.

**Saturation Modelling:** Saturation modeling was carried out stochastically using SGS technique. The property was populated using upscaled Saturation logs biased with facies as shown in Fig-11A & 11B

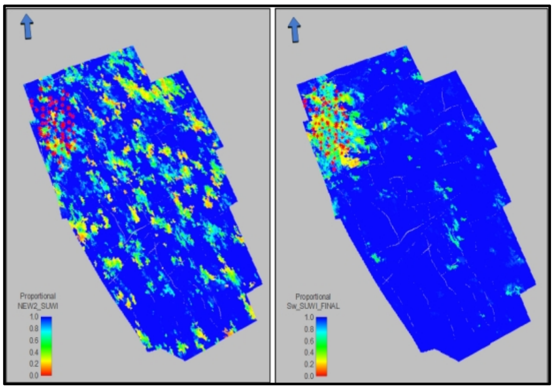
Fig-10A & 10B: Porosity modeling without and with trend maps using Sequential Gaussian Simulation.

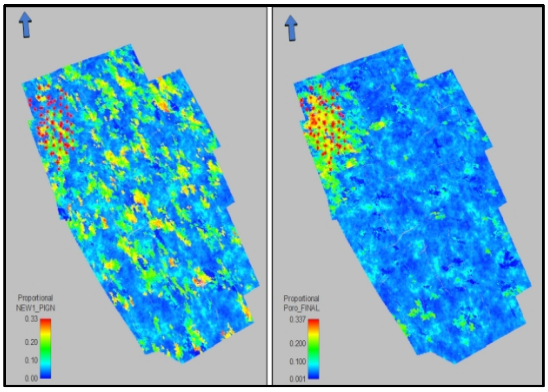
Fig-11A & 11B: Water saturation modeling without and with trend maps using Sequential Gaussian Simulation.

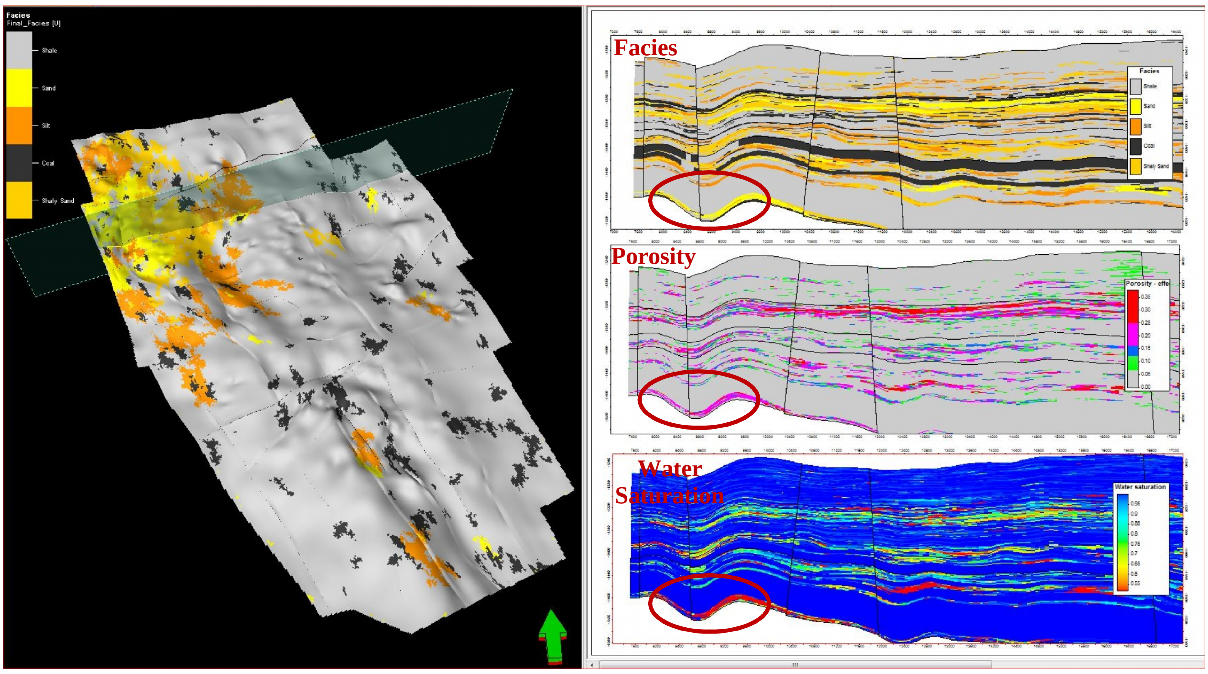


Fig-12A: Cross sectional view across the facies model showing facies distribution, which is well corroborated with porosity and water saturation in zone of interest.

**Results and Conclusion:**

This study has clearly brought out a regional facies trend based on available log data and well performance with geological understanding.in the absence of seismic attribute these trend maps are the only tool which can guide the Geostatistical methods to propagate the reservoir facies and property in proper direction and their values. The study has also given a comparison of using SGS methods based on variogram and VPC with respect to SGS methods with trend maps. The method used with trend maps has given satisfactory answer with the well performance of the sand. This process has given for optimum exploitation strategy of this brown field and right estimation of in-place reserves.

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

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