Identification of regional depositional trend through 3D variogram analysis for realistic property population with pixel based stochastic methods in clastic reservoir: A Case Study

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Summary

Regional depositional trend of the geological formations during and after sedimentary deposition play a crucial role in terms of lithofacies connectivity and heterogeneity. This process will not only help to define shape, size and orientation of different lithofacies but also help in petrophysical property population in 3D reservoir modeling. To capture the facies architecture, its connectivity, size, shape, orientation, proportion and distribution, various methods have been adopted in industry. Conceptual geological model based on geological understanding and sediment depositional trend identification has been popular over the year but this has the limitation of subjectivity of the conceptualization of the model with individual. To overcome this problem, geostatistical techniques supported by geological concept is widely accepted in the industry to build the realistic model. Geostatistics is an indispensable tool and technology for reservoir description which deals with the spatial relationship between data point in the geological context. These tools and technologies works on the numerical values of the property in the geological formation recorded by different type of tools and methods. This also provides logical, numerical model close to realistic behavior of the strata in sedimentary process thus reducing uncertainty in reservoir property population.

The present study deals with identification of regional depositional trend of two pay sands i.e. Kalol-II and Kalol-XII and implementations of this trend for population of reservoir property in heterogeneous reservoir. Regional trend have been identified through variogram analysis, sedimentological and log studies. The reservoir parameters have been populated using pixel based SGS techniques incorporating the regional trend of the strata to build more realistic property model for development plan. This study demonstrate methodology and workflow though judicious combination of geological analysis and geostatistical tools leading to reservoir property population in 3D space to build a robust geological model for better field development planning and hydrocarbon exploitation.

Introduction

The present study deals with identification of regional depositional trend for Kalol-II and Kalol-XII pay sands using geological information and geostatistical tools to build a robust 3D model.

Aim of study

The poor quality of seismic data and seismic derived attribute are unable to give the geometry of the sand body distribution, therefore the conceptual geological model is the only way to define the distribution pattern of the reservoir in the area. Thus present study aims to identify depositional trend of K-II & K-XII reservoirs sands through 3D variogram analysis of Kalol field. If this model is supported by the observed/recoded log and the conceptual model data then it will give a confidence for planning the development strategy of the field.

Study area

The Kalol Field (Fig: 1) is located in the northern part of Cambay Basin which is a well explored rift basin on the

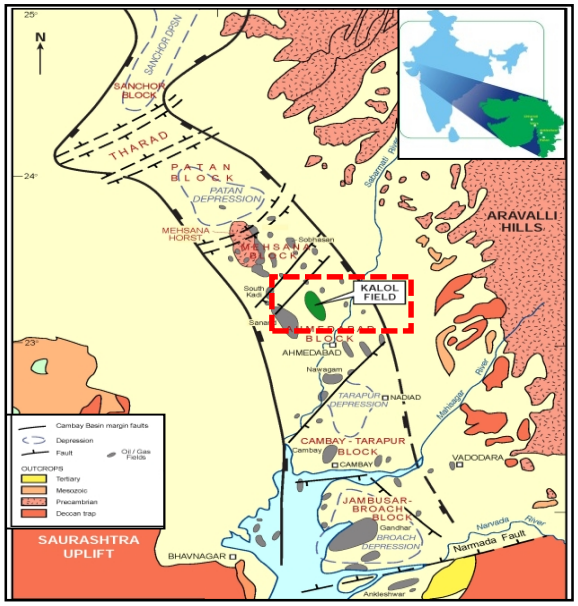

Fig: 1. Location map of study area

western margin of Indian platform. It is located around 20 Km NNW of Ahmedabad city. The field is spread over 350 Km^2. and is situated in the Ahmedabad–Mehsana tectonic block. The field is a highly faulted anticlinal structure, formed by a combination of regional Oligocene transpression and differential compaction over a Paleogene basement high. The hydrocarbons occur primarily in fluvio-deltaic sandstones and fractured coals of the Middle Eocene Kalol Formation.

Depositional Environment

The Kalol Formation comprises inter bedded sandstones, siltstones, sideritic, pyritic and Carbonaceous shale, and coals deposited in freshwater, intertidal-flat, brackish and shallow marine environments, as indicated by common palynomorphs, dinoflagellates, acritarchs and local fresh water ostracods (Bhandari and Chowdary,1975; Chowdhary and Singh, 1978).

The variations in relative sea-level, causing transgressive/regressive shifts in the paleo shore line and associated facies belts, gives rise to almost cyclical sedimentary stacking patterns, which often results in multi-pay, stacked reservoir systems like Kalol field.

In the present study the K-II sands and K-XII pays considered in the study have localized presence in the field. The K-II pay is situated in the central part of the field with almost E-W orientation and is deposited in transgressive bar / mouth bar environment. This reservoir facies is having good porosity and permeability. The K-XII sand is localized in the NW part of the field is conceptualized as distributary channel to intertidal deposit. The sand quality in this reservoir is also having good porosity and permeability.

Work flow

In the context of the complexities of the field an in-depth understanding of Geological process is required. The conceptualized geological model is prepared based on available geoscientific data i.e. sedimentological study, seismic, log and reservoir pressure /production data. This data driven model should satisfy the conceptual model and thus will have a high level of confidence for envisaging the intricacy of the field behavior. The final model thus obtain will help for facies modeling and property modeling process and thus reducing uncertainty in 3D space. The following work flow has been adopted:

- Log correlation
- Geological Maps/ Production map (bubble map)
- Data Analysis (Variogram/ VPC)
- Facies Modelling for validation

Log Correlation

To understand the lateral facies distribution log correlation has been attempted in various directions for K-II (Fig: 2A & 2B) and K-XII pay (Fig: 3A& 3B). Based on these correlations a conceptualized geological model has been formulized as depicted in Fig 2 & 3. Since the sands are not extensive in nature there correlation is also a challenging task. To compensate this processed log output validated with the production performance has been taken into account to define the geometry of these thin sands in entire area.

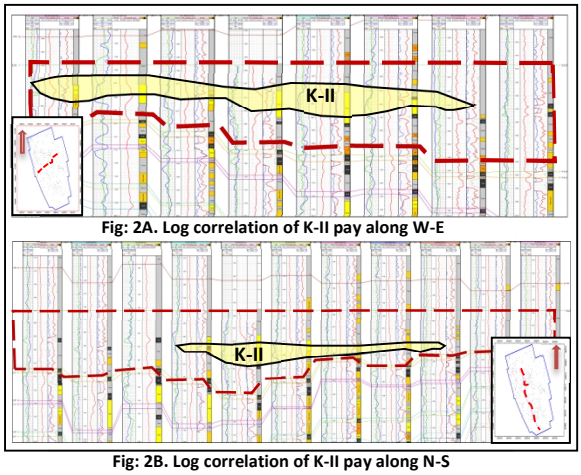

Fig: 2A. Log correlation of K-II pay along W-E

Fig: 2B. Log correlation of K-II pay along N-S

The correlation of K-II pay shows that the reservoir extends in W-E direction whereas in the N-S direction the reservoir is not developed as depicted in Fig: 2A & 2B. It is located in the central region only.

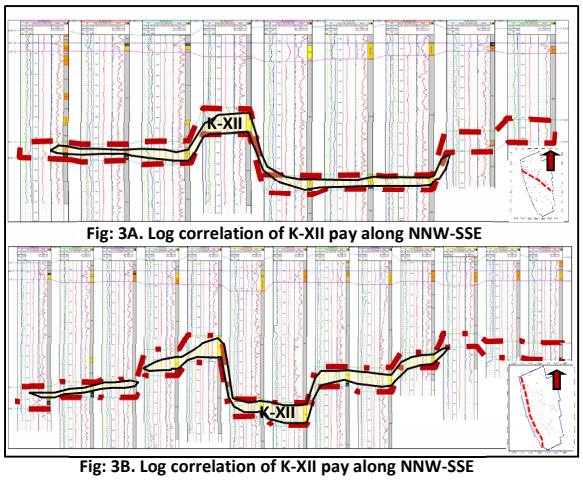

Fig: 3A. Log correlation of K-XII pay along NNW-SSE

Fig: 3B. Log correlation of K-XII pay along NNW-SSE

Similarly the correlation of K-XII sand shows that this reservoir is limited to the NW part of the field only.

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Geological Maps and Production map (Bubble Map)

The conceptual sand maps based on geological understanding and the available information from the wells is depicted in Fig: 4A & 4B. The orientation of K-II sand is almost W-E which is perpendicular to the orientation sediment input direction. Thus this sand is thought to be bar sand deposited parallel to the coast. The fig 4B shows the sand orientation of K-XII which is localized in the NW part of the field and assumed to be intertidal distributary channel. The bubble maps shows similar trend of reservoir distribution as shown in fig: 5A and fig: 5B.

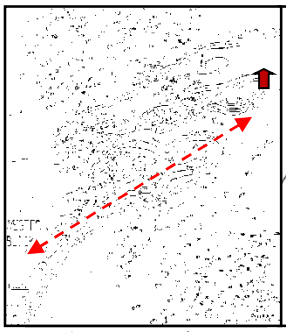

Fig: 4A. K-II Sand Map

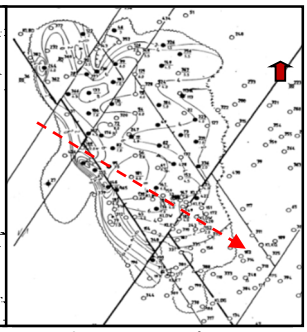

Fig: 4B. K-XII Sand Map

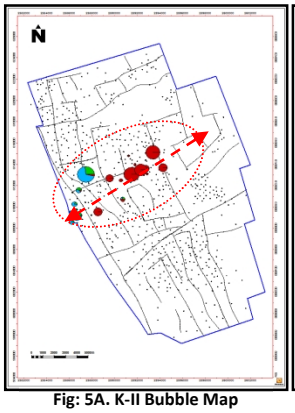

Fig: 5A. K-II Bubble Map

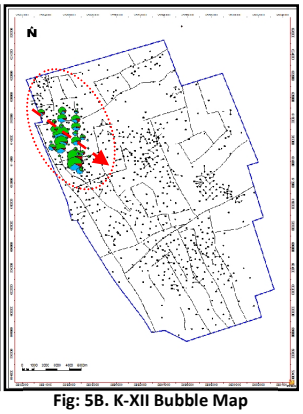

Fig: 5B. K-XII Bubble Map

Data Analysis

Spatial Continuity analysis (Variogram)

Variation of the property in 3D space is a function of the separation distance between data points, therefore spatial statistics depends on the relative position of the data to each other. Variogram is a very strong quantitative descriptive tool which measures the variation of property amongst the data points in space. This tool is based on the principle that two points close together are more likely to have similar value than points far away from each other.

Classical statistical analysis cannot properly address the spatial continuity and directionality inherent in geological data. Thus, we require a model describing the continuity, anisotropy, and azimuthal properties in the data.

For each azimuth and lag (separation) distance studied, all measured values can be spatially correlated and expressed as a statistical value known as variogram (Y)

$$\gamma(h) = \frac{\sum(Z(xi) - Z(xi+h))^2}{2n}$$

Where:

$Z(x_i)$=the sample value at location x_i;

$Z(x_i+h)$= the sample value at location x_i+h,

h = the lag distance and n= no of data point

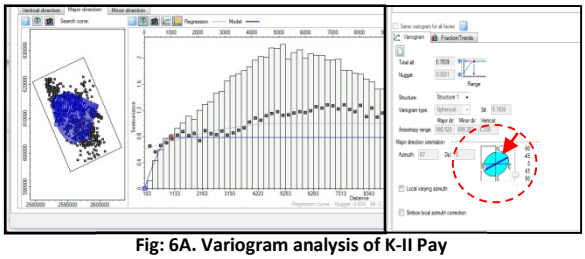

Fig: 6A. Variogram analysis of K-II Pay

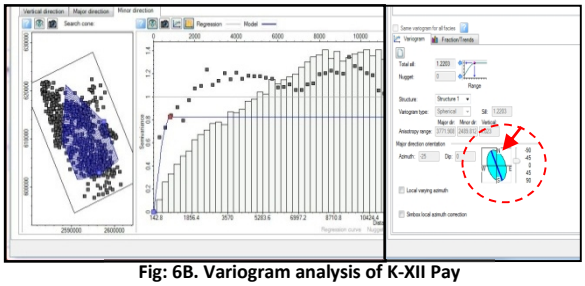

Fig: 6B. Variogram analysis of K-XII Pay

Intensive variogram analysis in vertical and horizontal /major/ minor directions for all facies have been done for K-II and K-XII pay zones keeping in view of the layering scheme, vertical and horizontal variability and direction of sediments etc. These variogram analyses have been used in population of different facies and petrophysical properties. To depict the geological process both during and after deposition facies modeling play a vital role. It will not only describe the deposition pattern but also help to populate the right reservoir property in right place which accounts for optimal exploitation of the reservoir. To capture the reservoir architecture with flow unit and barriers a stochastic pixel based method based on Sequential Indicator Simulation trend has been adopted which is depicted in fig: 6A for K-II reservoir and fig: 6B for K-XII reservoir facies. These figures have brought out a composite effect of all the three variogram i.e. vertical, horizontal, major/minor to depict the maximum correlation direction of sediment marked by circle in figure above. The

figure 6A & B shows SW-NE direction and NW-SE direction of the reservoir which corroborates the conceptual geological model, thus increasing confidence level.

Vertical Proportion Curve (VPC)

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 Vertical Proportion Curve in which volume fraction for facies will be a constant value within each horizontal layer of the grid. With this combination the volume fraction steering for each facies will steer towards a volume fraction defined by Vertical Proportion Curve as shown in fig:7A for K-II and fig: 7B for K-XII sand.

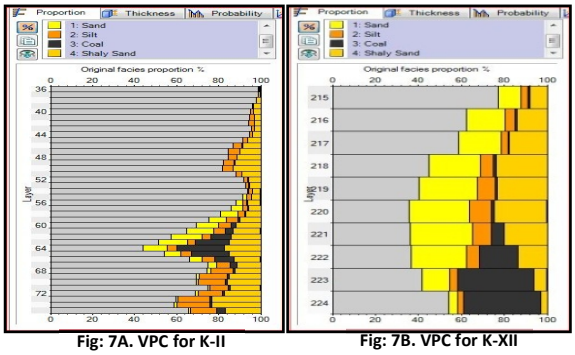

Fig: 7A. VPC for K-II

Fig: 7B. VPC for K-XII

Facies modeling for validation

Sequential Indicator Simulation method was used for propagation of facies in the entire 3D zone of each sand using variogram /VPC and probability distribution function on the upscaled facies log. 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.

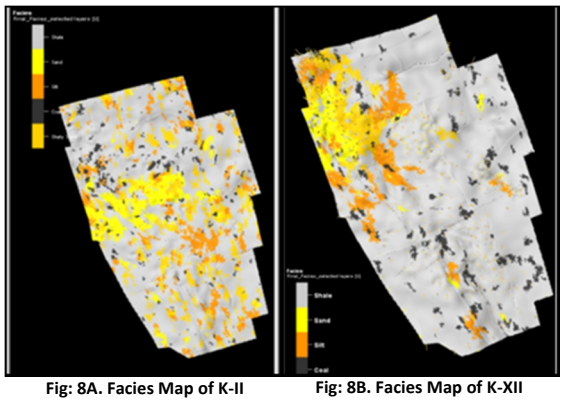

Fig: 8A. Facies Map of K-II

Fig: 8B. Facies Map of K-XII

Thus the facies model generated using the above method for K-II and K-XII sands is shown in fig 7A&7B. The propagation of properties in K-II sand and K-XII as seen in the model is similar to the sand maps created conceptually. These populated facies have been validated in those wells which were not taken in model and were found satisfactory.

Conclusions

In the absence of seismic attribute as guiding tool for identification regional trend of facies distribution, the conceptual geological model based on available log data and validated with data analysis trend using geostatistical techniques has given a lead for facies modeling. This facies model has been used for modeling of petro-physical properties leading to IIOP estimation. This study is an attempt to formulize a geological model based on data analysis which explains the reservoir orientation and of the reservoir sands which will provide lead for further exploration and exploitation..

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