RESERVOIR CHARACTERIZATION USING COLLOCATED COKRIGING AND COLLOCATED COSIMULATION – AN EXAMPLE FROM KG BASIN, INDIA

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SUMMARY

Geostatistical methods are globally adopted to predict heterogeneous reservoir properties. In this study, an attempt has been made to predict Gamma (GR) & Porosity (NPHI) values using Collocated Cokriging method. Further, to achieve a statistically enriched output; Collocated Cosimulation has been implemented to generate equiprobable realizations of GR & NPHI. Finally, from these realizations standard interpretable maps (lower limit, upper limit, mean and standard deviation) are generated and results at well locations were analyzed for error estimation.

1. INTRODUCTION

Reservoir characterization is one of the key steps in present day prospectivity analysis for petroleum exploration. The approach includes the challenges towards finding petrophysical parameters like porosity, lithology, saturation etc.

The classical issue in the course of delineating and understanding the subsurface reservoir is to integrate seismic data, which is spatially fine-sampled but of lower resolution; with well-log data which is of high resolution but have a very sparse spatial distribution.

Geostatistical methods are widely accepted globally to address the challenges of reservoir characterization (Jain Vinay *et al.*, 2011). A key benefit of Geostatistical methods over deterministic approach is the ability to assess the uncertainty in the modeling process (Hirsche Keith *et al*., 1996)

In the present study an attempt has been made to predict two key log properties: Gamma Ray (GR) and Porosity (NPHI) through Geostatistical approach. Gamma Ray is well aided to infer on subsurface lithology; whereas Porosity gives a good assessment regarding the presence of reservoir facies and probable accumulation zones.

Kriging method has been used to spatially interpolate closely sampled seismically derived impedance data to finer grid to match the processing bin size. Whereas, Collocated Cokriging method has been used to predict the GR and NPHI value over the study area with the help of close-spatially sampled Seismic Impedance data and corresponding log property at well locations.

Kriging and Collocated Cokriging are geostatistical techniques used for interpolation / estimation purposes. Both methods are generalized forms of univariate and multivariate linear regression models, for estimation at a point, over an area, or within a volume. They are linear-weighted averaging methods, similar to other interpolation methods; however, their weights depend not only on distance, but also on the direction and orientation of the neighboring data to the measurement location.

Simulation is a widely accepted method to get a probabilistic and statistically enriched output. Collocated co-simulation has been used to predict well log data (GR and PHI) with the help of seismic impedance data, generating equiprobable realizations of GR and NPHI.

The present study has been done with the aim of predicting log properties (GR & NPHI) with the help of Seismic property (Acoustic Impedance) using above Geostatistical Techniques in Krishna – Godavari Basin area of India (Figure 1).

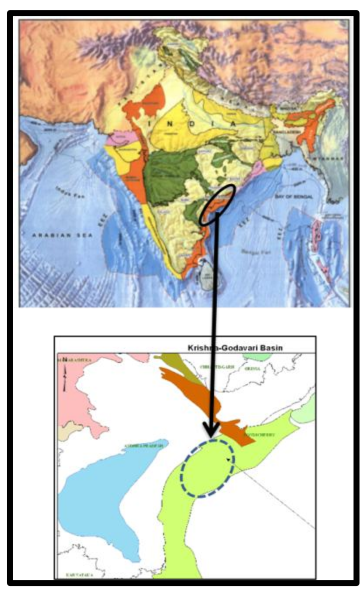

Figure 1: Location of Study Area

2. GENERAL GEOLOGY

The Krishna-Godavari Basin is located in the central part of the eastern passive continental margin of India.

The structural grain of the Basin is Northeast-Southwest. The Basin contains thick sequences of sediments with several cycles of deposition. A major delta with a thick, argillaceous facies, that has prograded seaward since the Late Cretaceous, is a hydrocarbon exploration target. The Basin is divided into Sub-Basins by fault-controlled ridges.

This proven petroliferous Basin has potential reservoirs ranging in Age from the Permian to the Pliocene. Good source rocks are known from sequences ranging in Age from Permian-Carboniferous to early Miocene. Because the reservoir sand bodies have limited lateral extents, understanding the stratigraphic and depositional sub environments in different sequences is essential to decipher the favorable locales for reservoir sands.

3. AVAILABLE DATABASE

A total of seven (7) wells are available in the study area. Most of the wells contain sufficient log set, for the evaluation (SONIC, GR, NPHI, RHOB etc.). The major formations identified are Matsyapuri Sandstone, Upper Vadaparru Shale, Middle Vadaparru Shale & Lower Vadaparru Shale (from Shallow to deep respectively). Testing results for two wells show presence of Gas at Top of Middle Vadaparru formation.

Based on the log interpreted formation tops, seismic markers have been mapped and Depth Structure maps have been prepared for all the correlated horizons Figure 2 shows a Depth Structure map for Middle Vadaparru top horizon with well locations marked.

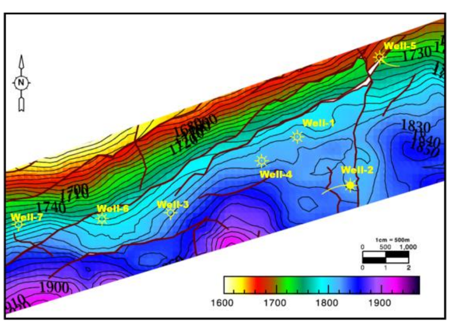

Figure 2: Depth Structure Map of Middle Vadaparru Top

The zone of interest for the present study has been preferred to be a 20 msec (6 msec above & 14 msec below) window around Middle Vadaparru top horizon. The likely gas accumulation is expected near the top of this formation in lenticular/localized sand bodies within shale.

Post Stack Inversion of seismic data has been carried out to generate inverted Seismic Impedance. RMS stratal slice was further extracted within the zone of interest; which has been used as the key input to predict well log properties across the study area.

The present study is anchored on three key geostatistical methods: Kriging, Collocated-Cokriging and Collocated Co-Simulation to predict key log parameters (GR & NPHI) across the study area. The succeeding section describes the brief concept and parameterization of the mentioned methods.

4. METHODOLOGY

4.1 Basic Workflow:

Seismic inverted Impedance is the key input for the present study. The Impedance volume has been exported in ASCII format in the zone of interest. The export has been done in every 2nd Inline & every 2nd Xline (50m x 50m).A 2D grid at 25X25m interval has been generated and this grid was populated through Kriging interpolation method.

Now to predict log properties, another dataset (ASCII format) has been made with the X-Y of 7 drilled well locations, average GR (Gamma Ray), NPHI (Neutron Porosity) and seismic impedance values within the study window at well locations. This dataset has been used as the guiding dataset for prediction of log properties across the study area using Collocated Co-Kriging method (Figure 3).

The interpolated Impedance grid generated through Kriging has also been used to predict GR & NPHI values throughout the area with probabilistic approach using Collocated-Co simulation method.

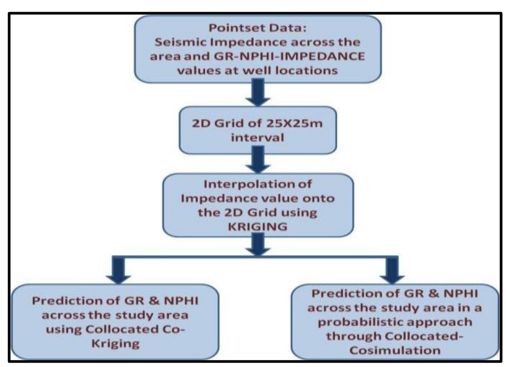

Figure 3: Workflow adopted in the present study

4.2 Kriging

4.2.1 Concept

The basic thought behind Kriging is to predict the value of a function at a given point by computing a weighted average of the known values of the same function in the neighborhood of the point. Kriging assigns weights according to data-driven weighting function. (Richard L. Chambers *et al*. 2000). It attempts to minimize the error variance. The basic tool for Kriging is Semivariogram, which quantifies the rate of change of reservoir properties with distance and direction. A Semivariogram is a plot of Variance between points at each azimuth & lag distance (Figure 4).

The variogram model tends to reach a plateau on the measured variance, called ***Sill*** at a distance called ***Range or Scale,*** which indicates the greatest distance over which the value at a point is related to the value at another point. Any discontinuity at the origin of the variogram is called ***"Nugget"***, which indicates random noise or short scale variability (Figure 5).

If the range computed for all the azimuths, vary in any particular direction, then Anisotropic/Azimuthal variogram analysis is being done and plotted as a rose diagram. For each direction, the variance is plotted as a function of distance. The major & minor axes represent the maximum & minimum scale of anisotropy (Figure 6).

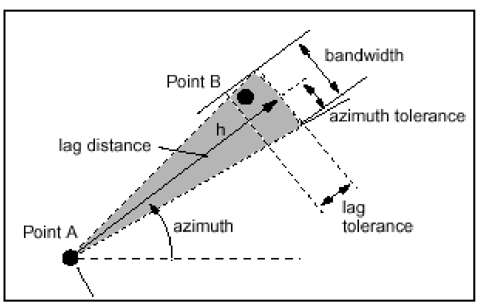

Figure 4: Variogram Parameters

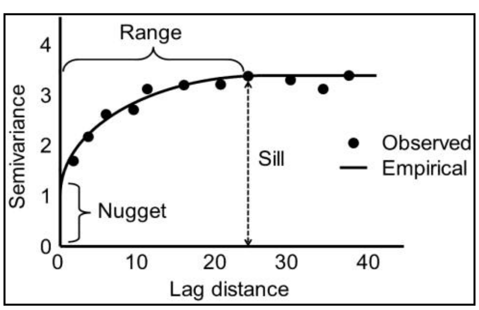

Figure 5: Semi-Variogram

In the present study ***Ordinary Kriging*** method has been adopted. This method uses a local mean during the interpolation. This local mean is assumed to be locally constant and is estimated using the data within the user-specified search neighborhood.

The search neighborhood parameter is guided by the Sill distance or Range of the variogram. A univariate model of spatial correlation is considered in the Ordinary Kriging method to guide the interpolation.

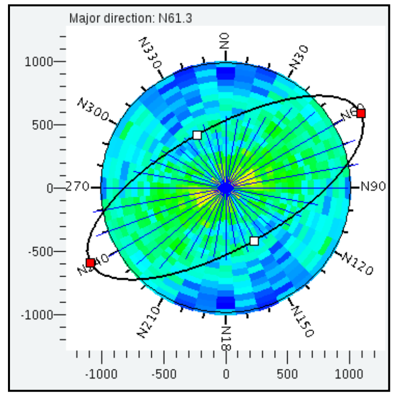

Figure 6: Azimuthal Semi-Variogram Rose diagram

4.2.2 Input Data & Parameters

2D Grid:
Cell Size: 25 x 25m

Variogram:
The data analysis shows no specific trend of decreasing or increasing data values; it's almost a chaotic spatial arrangement (Figure 7). Hence, an Omni-directional variogram has been used for the study.
The variogram shows a decent match with Exponential model with a major/minor scale of around 1043m and a local Sill of 1.01 (Figure 8).

Search Neighborhood:

As the variogram Sill comes around 1000m distance, a search neighborhood of 800m has been used; so that sufficient data points within variogram Range are used for weightage calculation.

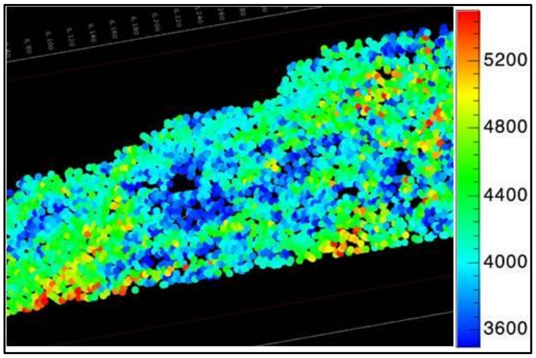

Figure 7: Data distribution – no noticeable trend

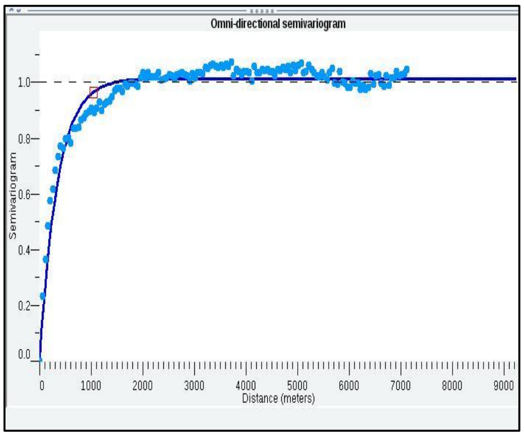

Figure 8: Variogram used in the present study

4.3 Collocated Cokriging

4.3.1 Concept

Collocated Cokriging method takes into account the covariance between two or more regionalized variable that are related; and apt to use when the primary attribute of interest is sparsely available (like log data); whereas secondary information, like seismic impedance is having dense spatial distribution.(Figure 9). (Babak Olena *et al*., 2008) Cokriging methods are multivariate extension of Kriging system of equations.

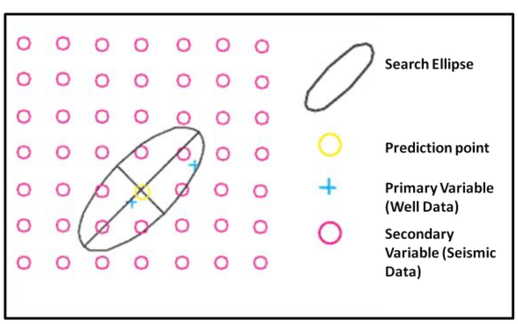

Figure 9: Collocated Cokriging Concept

4.3.2 Input Data & Parameters

Pointset data containing GR values, NPHI values and Seismic Impedance values at well locations has been used to guide to input grid of Seismic Impedance generated through Kriging interpolation to predict GR & NPHI across the study area.

Search neighborhood for the process has been guided through the variogram of impedance data.

4.4 Collocated Co-Simulation

4.4.1 Concept

Geostatistical simulation is well accepted in the hydrocarbon industry for characterizing heterogeneous reservoirs. Geostatistical simulation methods preserve the variance observed in the data. Their stochastic approach allows calculation of multiple equally probable solutions or ***Realizations***, which can be post-processed to assess uncertainty.

Collocated Cosimulation is a method for supplementing a primary variable (Hohn M.E) with a secondary variable (both Normal Score Transformed data) generating equiprobable realizations of primary variable (log data like GR, NPHI in the present study). The Cosimulation process starts log property estimation from a random location within the data set and moves to next random location for subsequent estimation. While doing so, it considers previously estimated log property values within the neighborhood search radius as the primary data in estimation process, till it completes estimation at all available locations in the grid. This is one particular realization or outcome of the map. In next realization, the starting point is another random location and thus follows a different path through the data set and generates another equiprobable map output. Usually, 50 to 100 realizations are computed to achieve stable statistics (mean, standard deviation etc.).

In the present study, Turning Bands Collocated Cosimulation method has been used to generate equiprobable outputs of predicted GR & NPHI across the area. In turning bands simulation (one of the earliest simulation methods), unconditional simulations are created using a set of randomly distributed bands, or lines. (Mantoglou, A. *et. al*., 1982*)*

4.4.2 Input Data & Parameters

Normal Score Transformed Pointset data with GR, NPHI & Seismic Impedance values at well locations and the interpolated grid (through Kriging) of seismic impedance are the key input for Collocated Cosimulation.

5. RESULTS & CONCLUSION

- GR & NPHI maps have been generated using Collocated Cokriging method. The predicted values at well locations show a maximum difference upto 9%. The well locations don't coincide with the grid corners and Cokriging fits a smooth surface – these give rise to the observed difference in the GR & NPHI values (Table 1)
- To achieve a probabilistic & statistically enriched prediction, Collocated Cosimulation has been run to predict GR & NPHI. 100 equiprobable realizations have been generated.
- GR & NPHI values may be interpreted together to have a better definition of the reservoir. Figure 10 shows the input impedance map. Fig 11 & Fig 12 show the predicted GR & NPHI via Cokriging. method. Fig 13 shows some random realizations of GR resulted from Collocated Cosimulation.
- Outcome of Uncertainty analysis is given on Fig 14 & 15. Any location point can be expressed as having 68% chance of occurrence comprising a value in-between lower & upper limit with a mean value and standard deviation value e.g. From Table 1, there is a 68% chance that Well 1 will have a GR value between 57.96 & 63.06 with a standard deviation of 2.55 and a mean value of 60.51 of all 100 realizations. All these outputs at well locations are summarized in Table 1. It is interesting to note that at 5 out of 7 wells (71 %) recorded GR values are actually falling within lower and upper limit of prediction. This gives the measure of confidence at unknown locations away from wells.
- Well 2 (Gas-producing) shows a low GR (45) & low NPHI (0.16) value. Whereas, a water-sand zone (as per log interpretation) in Well 6 is also supported by the present study with a low GR (33.16) & higher NPHI value (0.34). Thus the maps nicely explain post drill analysis. However, a detailed analysis in conjunction with full 3D interpretation will add value to prospect evaluation. However in case of new location proposal for drilling, one need to consult other logs (mostly resistivity) to reduce uncertainty associated with NPHI.
- This method gives a fair control on the prediction of reservoir properties along with the assessment of uncertainty in the prediction.
- The study is data-driven; hence better the quality of data and abundance of well locations can improve the final output in a good scale

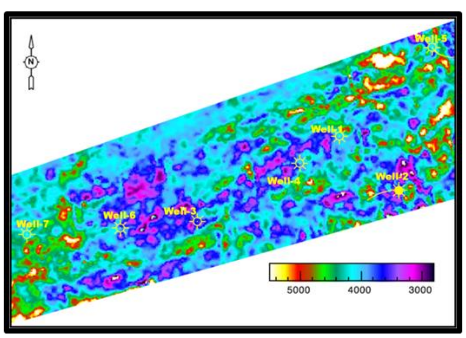

Figure 10: Impedance Map – using Kriging interpolation

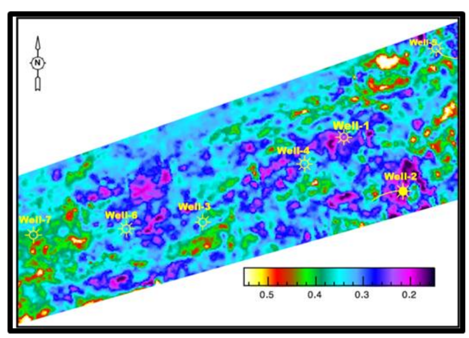

Figure 12: NPHI Map-predicted using Collocated Cokriging

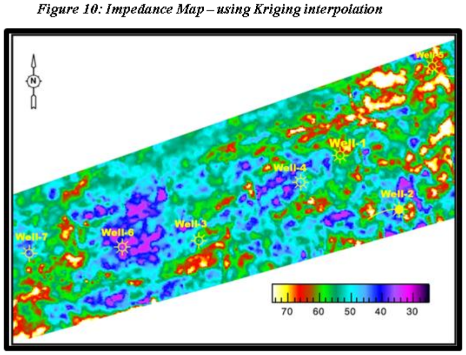

Figure 11: GR Map-predicted using Collocated Cokriging

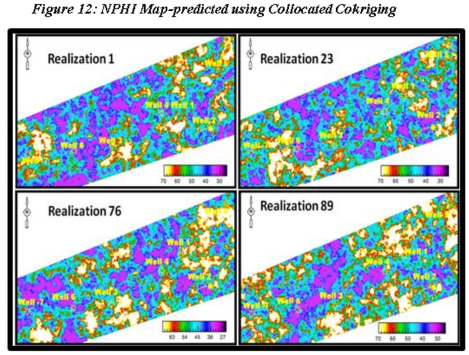

Figure 13: GR from Collocated Cosimulation- some random realizations

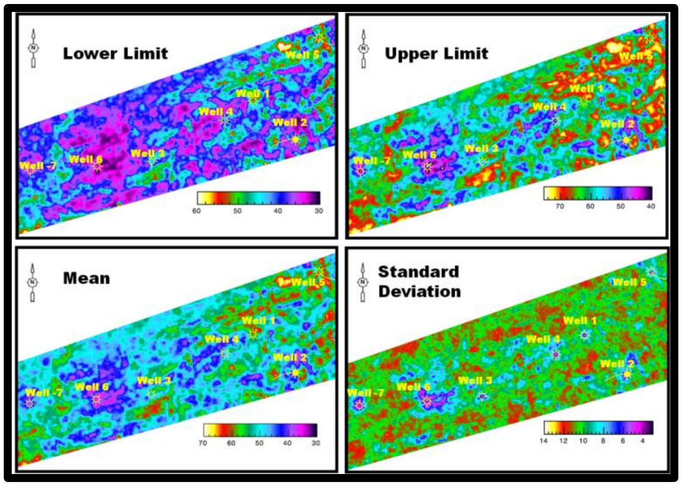

Figure 14: GR prediction from Collocated Cosimulation

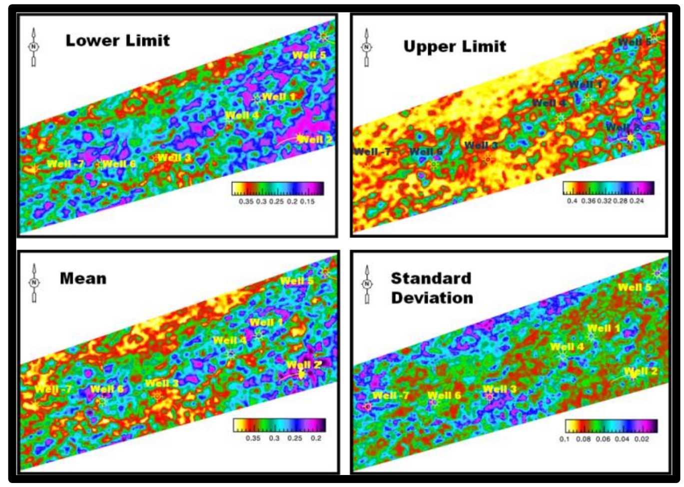

Figure 15: NPHI prediction from Collocated Cosimulation

Collocated Cokriging Results

Well	IMP	GR	NPHI	IMP_KRIG	IMP_Error %	GR_Pred	GR_Error%	NPHI_Pred	NPHI_Error %
Well 1	4142.25	62.40	0.23	4120.04	-0.54	61.83	-0.91	0.23	0.00
Well 2	3403.69	45.00	0.16	3204.62	-5.85	41.26	-8.31	0.16	0.00
Well 3	3691.11	57.00	0.38	3679.36	-0.32	55.76	-2.18	0.37	-2.63
Well 4	3992.42	48.00	0.34	3873.97	-2.97	46.13	-3.90	0.32	-5.88
Well 5	4438.65	72.00	0.36	4170.99	-6.03	65.27	-9.35	0.33	-7.56
Well 6	3922.88	33.16	0.34	3983.80	1.55	35.06	5.73	0.35	2.64
Well 7	4194.54	43.18	0.40	4182.22	-0.29	43.98	1.85	0.39	-1.27

Collocated Cosimulation Results with 100 realization

Well	IMP	GR	NPHI	GR_Simulation_Mean	GR_CI_Lwr	GR_CI_Upr	GR_SD	NPHI_Simulation_Mean	NPHI_CI_Lwr	NPHI_CI_Upr	NPHI_SD
Well 1	4142.25	62.40	0.23	60.51	57.96	63.06	2.55	0.21	0.18	0.23	0.02
Well 2	3403.69	45.00	0.16	40.96	37.55	44.38	3.42	0.16	0.16	0.16	0.00
Well 3	3691.11	57.00	0.38	51.81	45.37	58.24	6.43	0.36	0.34	0.38	0.02
Well 4	3992.42	48.00	0.34	46.18	43.04	49.32	3.14	0.26	0.21	0.31	0.05
Well 5	4438.65	72.00	0.36	59.48	52.49	66.46	6.98	0.32	0.27	0.37	0.05
Well 6	3922.88	33.16	0.34	36.26	33.23	39.28	3.03	0.34	0.32	0.36	0.02
Well 7	4194.54	43.18	0.40	39.19	35.17	43.21	4.02	0.38	0.37	0.39	0.01

Table 1: Results of Collocated Cokriging & Collocated Cosimulation

6. ACKNOWLEDGEMENT

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