

Enhancing Vertical Resolution and Reducing Uncertainties: A 3D Geostatistical Velocity Modelling Approach for Subsurface Analysis in the KG Basin

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Abstract:

The precise determination of a velocity model is of utmost importance in comprehending the subsurface topography, identifying hydrocarbon bearing zones and converting data domain. Although conventional velocity models are sufficient for data domain conversion, they lack the vertical resolution necessary to effectively resolve small-scale anomalies. As a result, seismic data exhibits limitations in highlighting small-scale topographical features. Furthermore, uncertainties in the structural interpretation can lead to erroneous structures or the oversight of hydrocarbon bearing zones. To address these challenges, statistical methods can be employed to reduce uncertainties and enhance resolution. These methods leverage the spatial similarity of geological properties to interpolate data. This paper introduces a 3D Geostatistical Velocity modeling approach that utilizes the Sequential Gaussian Simulation (SGS) algorithm to estimate a well-calibrated geostatistical interval velocity model in a shallow offshore area of KG basin. The methodology involves manual residual velocity picking at a fine grid resolution of 200m X 200m, followed by Time Preserving Tomography (TPT) and geostatistical modelling. The dominant reservoir in the area consists of thin hydrocarbon-bearing sands from the Cretaceous age, which are interspersed with silt and shale, making them indistinguishable in seismic data. However, the geostatistical velocity model, characterized by higher resolution, successfully resolves two thin sands (zone 1 and zone 2) measuring approximately 4-6m in thickness, which were inseparable on seismic data. This geostatistical high-resolution velocity model, when combined with other datasets, finds applications in identifying small-scale anomalies and predicting pore pressure, among other uses.

Introduction:

Seismic data plays a critical role in estimating subsurface velocities and is generated at different stages of processing, each identified by distinct terms such as Normal Moveout Velocity (NMO), RMS Velocity, Stacking Velocity, and Migration Velocity. It is

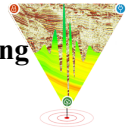
important to note that velocity is an inherent property unique to each rock type and cannot possess multiple values. However, determining the velocity of subsurface rocks is not possible directly. Therefore, empirical methods, relying on specific assumptions, are employed to estimate velocities for different formations within the layered subsurface.

The Geostatistical method utilizes 3D layered structures to generate volumes by employing 3D micro-structure Kriging, enabling interpolation between well logs and/or vertical velocity functions. Inputs for this method may include well logs, vertical velocity functions, maps, or a formation volume. In this study, primary inputs consisted of background RMS velocity, PSTM (Pre-Stack Time Migration) CDP (Common Depth Point) gathers and recorded sonic logs. While sonic logs were available for all wells in the study area, there were missing logs at shallow depths. To address this, a linear gradation approach incorporating water velocity and loose sediment velocity was employed to populate the missing zone.

For this study, 3D 3C (three-component) Ocean Bottom Node (OBN) Pre-stack time migrated gathers were utilized, incorporating offset data up to 55°. Prior to analysis, the seismic data underwent preprocessing to remove random noise through the implementation of the parabolic Radon transform. The Paradigm™ suite of software were employed to conduct this study and perform the necessary analyses.

Study Area:

The Krishna-Godavari Basin, situated on the rifted eastern margin of the Indian continental mass, is a Mesozoic Pericratonic extensional basin. Its formation can be attributed to the separation of the Indian continent from Antarctica during the Late Jurassic period. This rift event resulted in mechanical extension along the eastern margin, giving rise to the formation of horsts and grabens that trend northeast-southwest (Fig. 1). The study area is situated in the shallow waters of the KG Basin where the primary hydrocarbon reservoirs are Gollapalli sandstone/Syn-rift sediments, which date back to the Cretaceous period. The clastic sequence in the KG Offshore area, ranging from Tertiary to Cretaceous, was deposited in a Fluvial to marginal marine environment under high-pressure and high-temperature conditions. For reference, a generalized



lines with 35° mute angle and incorporated into the background velocity model. This resulted in an updated RMS velocity model. Fig-4 displays the seismic data before and after the residual velocity picking for four cross lines, specifically focusing on Inline 10574.

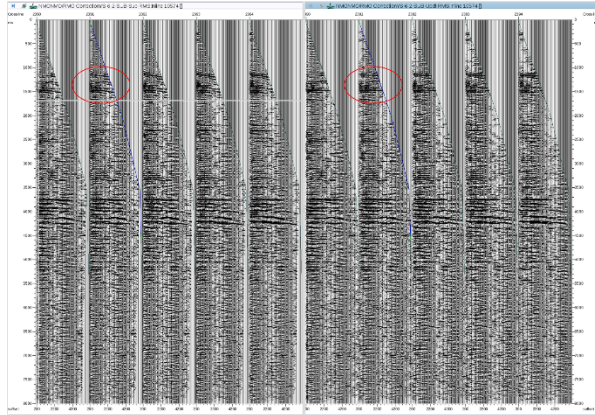


Fig- 4 Comparison of NMO Corrected Gather

Time Preserving Tomography (TPT):

Despite the improvements made by the updated RMS velocity model in flattening the seismic gathers, there remained a discrepancy between the well markers and the horizons in the depth domain. In order to align the well markers with the corresponding horizons, a technique called Time Preserving Tomography (TPT) was employed. This involved utilizing three horizons, namely Cretaceous, Albian and Barremian along with their respective well markers. To begin the TPT process, the updated RMS velocity model was transformed into an Interval velocity model using the Constrained Velocity Inversion (CVI) method. The time horizons were then converted to depth domain. At each well point, the misalignment or mis-tie between the horizon and the well marker was calculated and stored as a grid. For the purpose of model-based tomography, the depth horizons were saved as "pencils" (term used in the software) for the three markers. The tomography process assumed an isotropic medium. The Interval velocity model, along with the created pencils and the mis-tie grid, were utilized to construct a 3D matrix for model-based tomography. The objective was to align the horizons with the well markers while maintaining structural consistency and flatness of the seismic gathers. As a result of these iterations the difference between the well markers and the horizons was reduced in a structurally consistent manner and the horizons and well markers were satisfactorily tied together after five iterations. An updated interval velocity volume was generated, along with updated depth horizons for the three layers. To visualize the impact of the tomography, a seismic section was overlaid with the updated interval

velocity, both before and after the tomography process. These visual representations can be observed in Fig- 5 and 6.

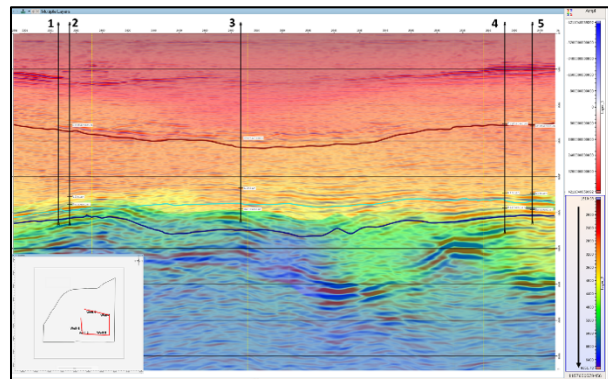


Fig-5 Velocity Section along wells before tomography

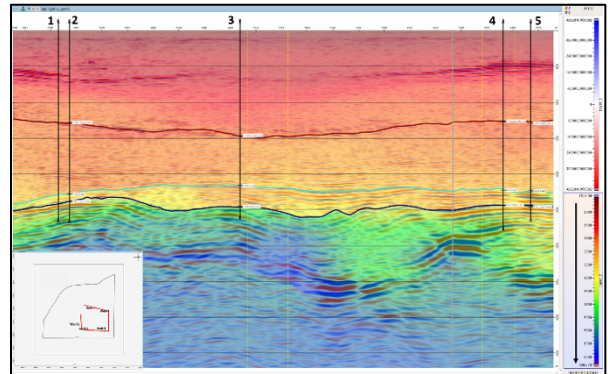


Fig- 6 Velocity Section along wells after tomography

Additionally, the impact of the tomography process at the well locations can be observed in Fig- 7. The figure illustrates the updated interval velocity at the well location, with the blue curve representing the recorded sonic velocity and the red curve representing the velocity extracted from the updated interval velocity model.

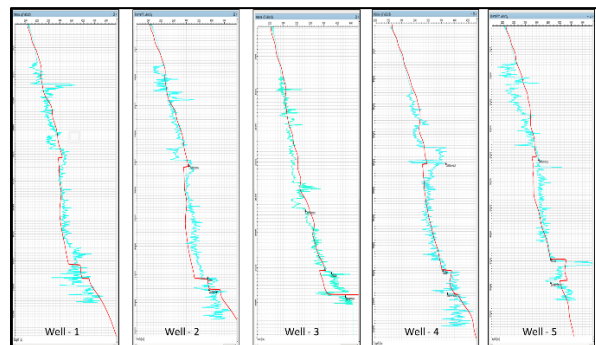
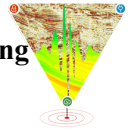


Fig- 7 Comparison of Sonic velocity and tomography velocity at well location

Although the updated interval velocity helped in flattening the gathers and aligning the markers, there still existed some variances between the sonic velocity



and the interval velocity. To address this, geostatistical velocity modeling was conducted, aiming to tie the sonic well velocity with the interval velocity and enhance the vertical resolution of the velocity model.

Geostatistical Population:

Geo-statistical techniques provide a valuable means to enhance the vertical resolution of velocity data by leveraging recorded sonic logs as hard constraints and incorporating the updated interval velocity model as a soft constraint. The process involves estimating the semi-variance at each data point and employing interpolation techniques such as kriging within 3D geostatistical models. The specific algorithm chosen for the geostatistical population depends on the distribution characteristics of the data.

To gain insights into the distribution patterns, a histogram analysis of the sonic log data recorded at five wells was performed, revealing a similarity to a normal distribution, as depicted in Fig- 8. In light of this observation, the Sequential Gaussian Simulation (SGS) methodology was selected as the appropriate approach. The data was then imported into the SKUA-GOCAD module of Paradigm™ software, which facilitated the geostatistical modeling process.

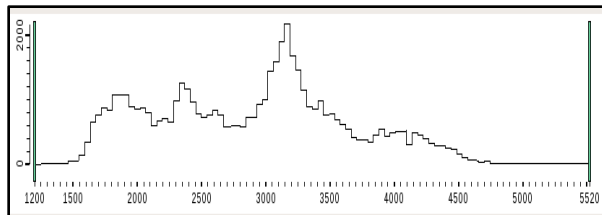


Fig- 8 Histogram of recorded sonic logs for 5 wells

A structural model comprising six layers was constructed to represent the subsurface. These layers were defined as follows: (1) zero depth to seafloor, (2) seafloor to cretaceous, (3) cretaceous to albian, (4) albian to barreman, (5) barreman to basement, and (6) basement to a depth of 10,000 meters. For training the geostatistical model, four sonic logs obtained from wells 1, 3, 4, and 5 were utilized after undergoing conditioning and filtering. In order to evaluate the predictive performance of the algorithm, well 1 was designated as a blind well. The updated interval velocity model served as an external drift, aiding in the interpolation of data points located away from the wells.

All six layers were topologically proportional and semi-variograms were calculated for each layer. Since the wells did not penetrate the basement and the log data was conditioned starting from the seafloor, semi-variograms could only be computed for the four layers

above the basement. These four layers exhibited a similar range, indicating minimal lateral variation in the velocity data across the study area. Multiple parameters were tested to train the model, aiming to achieve optimal estimation accuracy at the input wells. Ultimately, the parameters yielding the best results were employed to generate a high-resolution interval velocity model. Fig- 9 showcases the negligible misalignment between the recorded sonic log and the velocity trace extracted from the geostatistical output for the four input wells as well as the blind well. The blue curve represents the recorded sonic log, while the red curve represents the velocity extracted from the geostatistical interval velocity model. This demonstrates the effectiveness of the geostatistical approach in capturing the vertical variations in velocity and achieving alignment with the recorded data.

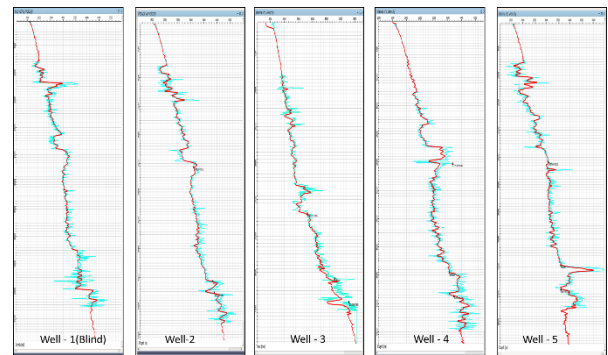


Fig- 9 Comparison of Sonic velocity and geostatistical velocity at well location

Result and Discussion:

The geostatistical inversion process has yielded velocity data with a resolution surpassing that of the seismic data, as evident in Fig- 9 at the well location. Additionally, individual layers can be distinguished in the velocity data, as observed in an arbitrary section passing through drilled wells in Fig- 10.

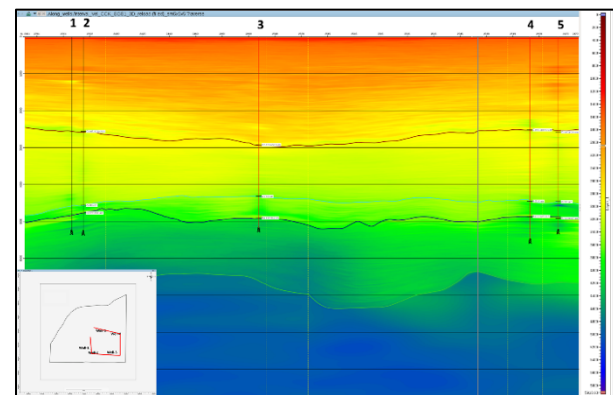
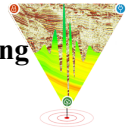


Fig-10 Geostatistical Velocity section passing through drilled wells

Among the wells, Well 5 and Well 2 have successfully produced gas from the cretaceous age reservoir.



However, other wells faced complications that prevented testing. In the study area, Zone 1 and Zone 2 represent two sands that have produced gas. In the velocity data, these two sands were not discernible, color scale was compressed within the range of 2500-5200 m/s to identify these two sand layers but still appeared inseparable as shown in Fig11.

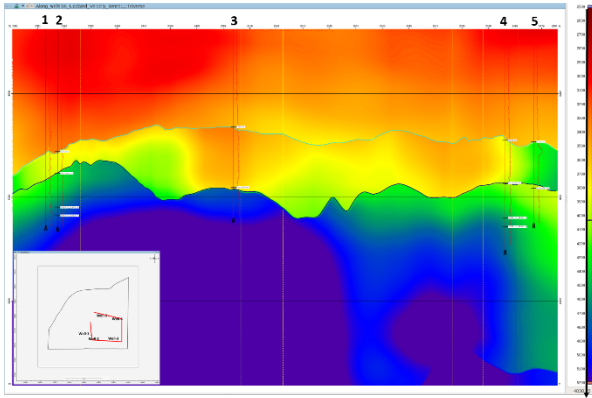


Fig- 11 Tomography Velocity section passing through drilled wells

However, the geostatistical velocity model was able to accurately resolve and differentiate the two sand layers, as depicted in Fig- 12. This compression allows for the clear separation of the sands and facilitates the tracking of their extensions within the geostatistical results.

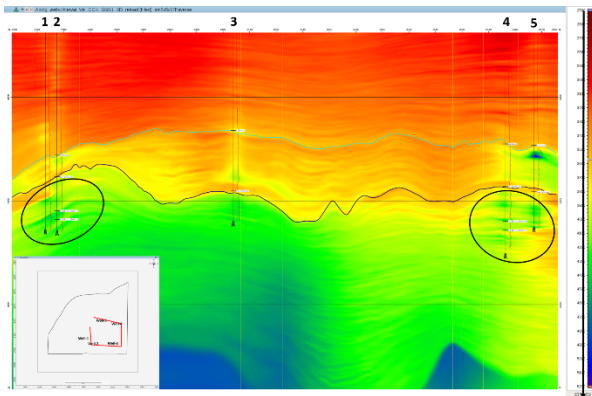


Fig-12 Geostatistical velocity section highlighting sands

Cretaceous age reservoir in the study area is very heterogeneous in nature with thin alternation of shale and sand. Reservoir sands are thin and at depth of around 5200m. At these depths, frequency in the data attenuated to frequency band of around 5-25Hz with peak frequency at around 15Hz. Reservoir sand lies at the onset of positive amplitude of S-crossing in the gather data. Gather at gas bearing well were flattened with background RMS velocity, Updated RMS Velocity and geostatistical velocity and zoomed in the gas bearing zone to represent the effect of high resolution velocity as shown in Fig 13.

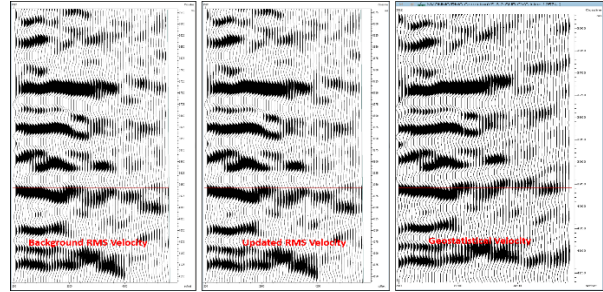


Fig- 13 NMO Corrected gather zoomed in the HC bearing zone for Well 2

In the study area, an attempt has been made to identify the class of reservoir sand. Amplitude Vs Offset plots for gas bearing at object level (marked as red line in Fig 13) were generated for NMO corrected gathers with three velocities as shown in Fig 14.

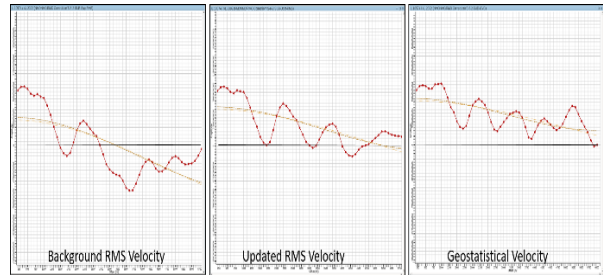


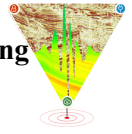
Fig-14 Amplitude Vs Offset Plot at Well 2 for gathers corrected with three velocities

As shown in Fig 14, at the outset it can be said that at gas bearing well 2, gather corrected with geostatistical velocity display anomaly similar to Class-I AVO anomaly. This may need further validation with more data sets and thorough analysis. In the nearby areas also, sands deposited in equivalent time display Class-I AVO anomaly. AVO class of the reservoir could not be characterized with conviction since serrated sands masks the effect of AVO in the study area.

The high-resolution velocity data reveals finer details, enabling the identification of small-scale features. By incorporating velocity data with other seismic attributes, a more comprehensive understanding of the area can be achieved, particularly in highlighting topography-related features such as channels and buildups.

Limitations:

Geostatistical methods inherently involve a certain level of uncertainty in each iteration. This uncertainty can be mitigated by training the model using larger datasets. When the model is well-trained with extensive training datasets, it leads to improved predictions of the property of interest. However, the availability of data poses a significant constraint in this study.



In the study area, only five wells were drilled, and these wells were concentrated in the south-eastern region. Out of these wells, only four could be utilized to train the geostatistical model, and just one well was available to test the output. The limited number of wells restricts the spatial coverage and reduces the ability to accurately assess the separation and extension of the two sand layers across the entire study area.

If a larger number of wells were scattered throughout the study area, it would have provided a more comprehensive representation of the subsurface conditions. This would have allowed for a more robust analysis of the separation and extension of the two sands throughout the entire study area, reducing uncertainties associated with limited well coverage.

Conclusion:

This paper introduced a 3D Geostatistical Velocity modeling approach using the Sequential Gaussian Simulation (SGS) algorithm to estimate a high-resolution interval velocity model in the KG basin's shallow offshore area. The methodology involved manual residual velocity picking, Time Preserving Tomography (TPT), and geostatistical modeling. The geostatistical velocity model successfully differentiated two previously undistinguishable thin sands (zone 1 and zone 2) that appeared merged in seismic data resolution, offering enhanced resolution compared to traditional velocity models. The high-resolution velocity model has valuable applications in detecting small-scale anomalies and predicting pore pressure. However, the study area was limited by the scarcity of data, with only five wells and limited coverage in the south-eastern region. More wells scattered throughout the area would provide better spatial coverage and reduce uncertainties in analyzing the separation and extension of sand layers. Overall, the geostatistical velocity modeling approach proved effective in improving the vertical resolution of velocity data and enhancing subsurface understanding in the KG basin. Further studies with broader data coverage are recommended to reduce uncertainties and enhance the accuracy of the velocity model.

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