Improved Resolution in Initial Interval Velocity model building by integrating well data and seismic data for depth imaging

Swati Singh*, Mithai Lal, R. L. Basak and Rajesh Madan
Western Onshore Basin, ONGC, Vadodara
singh_swati@ongc.co.in

Keywords
Geostatistical Approach, Kriging method, Variogram, 3D Global Tomography, Misties, Welltie Tomography.

Summary
In the recent era, PSDM is the utmost technique for precise subsurface imaging and velocity information. The dexterity to define an accurate interval velocity model and subsequently truthful subsurface imaging of the target reflectors is a key challenge in pre-stack depth imaging.

Persuasively, delineation of accurate interval velocity model is at the heart of every process we do in depth imaging so having all the inputs to ensure the velocity model is accurate, high resolution and geologically realistic is of highest importance. In PSDM we start with an initial model and refine this model for accurate subsurface imaging. There are many ways for preparing initial velocity model. Conventionally rms velocity is converted into interval velocity by dix method or adopting a more sophisticated and broadly used constrained velocity inversion method.

Objective of this paper is to illustrate the technique to prepare initial interval velocity model by integrating well, seismic and interpretation data with the help of geostatistics. The velocity model was then iteratively updated to converge to a final model through which final depth migration was run and subsequently welltie tomography was done for calibration with wells.

Introduction
Cambay-Kadi and Cambay-Kalol are the two recognized petroleum systems in the area of study. This consists of Cambay Shale Formation, the regional source rock, and sand/silt layers found within Older Cambay Shale, Mandhali, Mehsana and Kalol sections forming multi-layered reservoirs. Entrapment in the area is mostly strati-structural with faults playing a prominent role in forming traps for hydrocarbons. The main thrust of this work is to improve the imaging quality through precise interval velocity model which is predominantly necessary for accurate imaging and true positioning of seismic events which in turn gives the confidence in well planning for hydrocarbon exploration and production.

To estimate the truthful velocity depth model an initial model was prepared by combining all the geophysical and geological data available in Langhnaj-Wadasma area of Cambay Basin. In addition to rms velocity, we have used well logs specifically sonic log and seismic horizons to generate an initial velocity model which is more geological contrived. Later in this study, the Interval velocity model was then updated through 3D Global tomography driven iterations and finally welltie tomography was done for depth matching and minimizing mis-ties.

Theory
Geostatistical method uses layered structures in 3D to create volumes with different properties by performing 3D microstructure kriging to interpolate between well logs or vertical velocity functions. The input to volume creation is well logs, or vertical velocity functions and maps, or a formation volume. The 3D structure can be defined using constant time/depth values, time migrated or depth 3D interpretation maps, or formation volumes as input. Well logs can also be used to create volumes in the time migrated or depth domain. In case of time-migrated domain, the well data must contain time-depth relations.

For interpolation kriging is used to obtain the statistically optimal interpolation of input data. Kriging is based on the assumption that there is a spatial dependency between geological properties at separate points in an area and that this spatial dependency is a function of the distance between the
Improved Resolution in Initial Interval Velocity model building by integrating well data and seismic data

points. The statistical measure that expresses the rate of change in point values in relation to distance is the semivariance. Semivariances are calculated for different distances between points and the results are plotted in a semivariogram, which is then used to calculate the weighting coefficients for kriging interpolation. The semivariogram determines the extent of variance of an unknown value of one point from the known value of a different point, depending upon its distance from the known point. There are several methods available for kriging one of the method is Collocated Cokriging which requires, an additional input, an external drift volume to guide the interpolation between well or vertical function locations. This method was used in the study. In collocated cokriging, the trend is a slope of regression on a variable given by the coefficient of proportionality of the cross-correlation model. It allows to control the influence of secondary data on the kriging estimation by selecting the value of the data correlation factor between primary and secondary variables.

Kriging interpolation in Geostatistical Volume generation is performed in two stages- Selection of an optimal semivariogram, interpolation of the data using kriging (calculate the weight coefficients for each control point). The semivariogram used for kriging is estimated in two steps- calculating the experimental semivariogram from input data points and modeling the semivariogram by finding the best fit among two theoretical semivariogram models - exponential or spherical, to create the theoretical function which will be used in kriging.

Methodology

Geostatistical method was used in generating velocity volume. This technique has helped in capturing small spatial variation in velocity & thus to enhance the resolution in seismic imaging.

In present study sixty wells were used as shown in Figure 1. Here well velocity in addition to seismic velocity was used in preparation of initial interval velocity model building. Inputs to volume creation are structural maps, sonic log and seismically derived rms velocities. Since well data is sparsely located so for lateral propagation of velocities secondary trend of rms velocity was used.

Figure 1: Index Map (Left) & Base Map of study area showing distribution of wells used in study (Right).

Before using the RMS velocities, correlation of sonic velocity and RMS velocity (converted to interval velocity) was compared for quality check whether the trend of the two are following each other or not (Figure 2). Since the correlation between the two was good therefore it was used for the secondary trend. Collocated kriging was used for guiding the interpolation between wells.

Figure 2: Comparison of sonic velocity (pink) and Interval velocity converted from RMS velocity (green) along the wellbore. Since the correlation between the two is good hence secondary trend of RMS velocity can be used in interpolation.

Before using sonic log in the study quality check was done as follows:
Improved Resolution in Initial Interval Velocity model building by integrating well data and seismic data

- Edit the sonic digits for null/improbable values.
- Depth correction was done, if any.
- Quality check was done against the bad borehole conditions and effective measures were taken.

The basic workflow for this method is as follows:

1. Sonic Log
2. Log Conditioning
3. Define Structural Maps
4. Layer wise Variogram analysis
5. Collocated cokriging with RMS Velocity
6. Initial Depth Vel. Model

The logs usually contain very high frequencies which need to be de-spiked and filtered out before use. In the current study, eight layers model H-1 to H-8 are defined viz, first dummy layer (between zero depth horizon and H-1 top), Other layers are Tarapur shale, Kalol formation, Mehsana member, Mandhali member, OCS and two dummy layers (between OCS & H-7 and between H-7 & H-8). Layer topology proportional to top and bottom defines the layer geometry. Geological formation volume built by these eight layers is shown in figure 4. As well logs were not available in the dummy layers, RMS velocities were used. For layers Tarapur, Kalol, Mehsana, Mandhali and OCS, Sonic velocities were used with secondary trend of RMS velocity. Kriging method was used for interpolation.

The statistical measure that expresses the rate of change in point values in relation to distance is called semivariogram. At least two well logs must intersect with the layer to produce a semivariogram. For each layer variogram analysis was done for interpolation. - Semivariogram model for a layer is shown in figure 5. This procedure was repeated for every layer to obtain initial depth interval velocity model. It was observed that trend of the velocity in the velocity volume is conformable with the filtered trend of sonic log variations.

The Initial Interval Velocity model building using Geostatistical method was adopted in Langhnaj-Wadasma area in Cambay Basin to map better seismic image for strati-structural prospect within Kalol to OCS level. We compared the initial velocity
Improved Resolution in Initial Interval Velocity model building by integrating well data and seismic data

volume generated by conventional CVI (constrained velocity inversion) method and geostatistical method, the latter was showing the detailed velocity variation as per sonic log variations as shown in figure 6 and 7 respectively.

With geostatistical velocity and CVI interval velocity, six isotropic tomographic iterations were done respectively for the final velocity model. Both the velocities are shown in figure 8 & 9, it is observed that the initial as well as final velocity model showing the trend as per velocity variation in the sonic log as compared to the conventional velocity model.

![Figure 6: Initial interval Velocity volume created by CVI (constrained velocity inversion) Method.](image1)
![Figure 7: Initial interval Velocity volume created by Geostatistical Method.](image2)
![Figure 8: Final interval Velocity volume after six isotropic tomographic iterations (used initial velocity prepared by CVI method).](image3)
![Figure 9: Final interval Velocity volume after six isotropic tomographic iterations (used initial Velocity prepared by Geostatistical method).](image4)

Successive iterative processes were adopted progressively for the velocity depth refinement through tomography. After achieving the precise interval velocity model through six iterations, final isotropic Pre-Stack Depth Migration was carried out. Final PSDM gather obtained by Kirchhoff’s migration are also compared in figure 10 & 11. The gather using geostatistical velocity model is showing better flatness and depth relation. Final PSDM stack scale to time section is compared with PSTM stack in figure 12 which replicate better imaging in fault shadow zone due to better capture of lateral and vertical variations in velocity model with the help of sonic log.
Improved Resolution in Initial Interval Velocity model building by integrating well data and seismic data

Fine tuning of velocity model was done by two iterations of welltie tomography inversions for minimizing the misties between horizons and well markers. Comparison of sonic velocity with PSDM Velocity and welltie velocity is shown in figure 13. This shows the Final velocity not only produces good well marker match, it also produces comprehensive geological velocity.

Figure 10: Final PSDM Gather, after six isotropic tomographic iterations (used initial velocity prepared by CVI method).

Figure 11: Final PSDM Gather, after six isotropic tomographic iterations (used initial velocity prepared by Geostatistical method).

Figure 12: Comparison of PSTM (Left) and PSDM scale to time stack (Right).

Figure 13: Showing comparison of sonic velocity with PSDM and welltie velocity.

Conclusions

➢ Integration of well data with seismic data has brought out the detailed variation in velocity laterally as well as temporally.
➢ The velocity so obtained is not only geophysical velocity but representing geology. Final velocity volume also confirms the trend of log which will now provide value addition in detailed findings.
➢ Fine tuning of velocity model could be more accurate when more well logs are to be included in this Geostatistical method.
➢ Consecutively, the welltie tomography was proficient enough to correct the mis-ties between seismic and available well markers resulting fine tuning of both interval velocity and depth model.
➢ PSDM seismic data has meticulously imaged and brought out noticeable improvement compared to earlier data. This enhanced output will definitely provide better confidence to the interpreter’s literal need for the critical subsurface delineation and well planning.
Improved Resolution in Initial Interval Velocity model building by integrating well data and seismic data

References


Model based depth imaging by Stuart Fugin, course note series No 10 (SEG).


Geoff Bohling, KRIGING, C&PE 940, 19 October 2005.


Online help of Paradigm documentation.

Acknowledgements

The authors express their deep sense of gratitude & sincerely thank to Shri H Madhavan, GGM-Basin Manager–Western Onshore Basin and Shri Matibar Singh, GGM-HGS, Western Onshore Basin, ONGC, Vadodara for their guidance and encouragement and permitting to publish this paper.

The authors also express sincere thanks to Shri Radakishan Gupta, Ex-CGM (Geol) and Shri Ramashray Yadav, DGM(GP) of Block-III, Western Onshore Basin, ONGC, Vadodara for their valuable suggestions & interaction during this work.

Authors are thankful to colleagues, software & hardware groups for their constant support in this project.

Views expressed in this paper are that of the author (s) only and may not necessarily be of ONGC.