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Stochastic Seismic Inversion for Delineation of thin Sand Reservoir within Kalol Formation, Cambay basin, Gujarat

Abstract

One of the major challenges in development of channel sand reservoir is to delineate these reservoirs. In cases of thin reservoirs, it becomes even a more challenging to find out reservoir areal extent and to place next appraisal/development well with a confidence. This paper is being put up as a case study carried out on an exploratory block in Cambay basin. The presence of thin reservoir is very common in the study area. Deterministic inversion carried out is again limited by its vertical resolution and non-uniqueness. The elastic properties derived from this analysis could not be used confidently specially in cases of thin reservoir. The Stochastic seismic inversion technique integrates the fine vertical sampling of well data and lateral sampling from Seismic data, produces a high-resolution elastic property which can optimally be used for delineation of thin reservoir for its areal extent. Both the inversion methods are applied in the present case study and suggest that stochastic inversion is best suited for delineation of thin reservoir which helps in optimizing appraisal/development locations. The quality control checks at intermediate steps of Inversion process have to be rigorously done and care should be exercised while interpreting the inversion results, taking support from other available data. The study has been carried out on Hampson-Russell suite of software.

Location Map of the study area

Study area is situated in the vicinity of the Eastern Basin Margin of the Ahmedabad sector of the Ahmedabad – Mehsana tectonic block, one of the most prolific producing blocks in the Cambay Basin, Gujarat. Location map of study area is shown in Figure-1.

Figure-1: Location map showing study area (Source: Public domain)

Geology of the Area

STUDY AREA

The Cambay Basin is one of the oldest hydrocarbon producing basins in India. It is an intracratonic rift basin. The crustal extensions related with the passage of the Indian Plate over the Reunion Hotspot, during the terminal Cretaceous times, eventually led to the formation of the Cambay Basin. Sedimentation in the basin started during the Early Paleocene and continue to Present. The earliest marine sediments in the basin are recorded during the Late Paleocene and seve marine transgressions are recorded from this time till the Miocene. The transgressive episodes are separated by periods of regression during which marginal marine to fluvial sedimentation is recorded.

The study area lies in the Ahmedabad – Mehsana tectonic block which is one of the most prolific producing blocks in the Cambay Basin. It is bounded on the north by the Patan-Unawa / Saraswati cross trends, while in the south it is bounded by the Vatrak cross trend.

The Cambay Shale– Kalol Formation is the main petroleum System in the area. Cambay Shale in the lows forms a mature kitchen in this area. The main reservoir lies in various interval in Kalol formation. Compaction related faults are seen in between Kalol Top to K-VI+VII Top. The Tarapur Shale acts as a regional seal in the area, while intraformational shales in these formations act as local seals.

Challenges in the Study Area

In the pursuit of finding the hydrocarbon in the study area, six exploration wells have been drilled. While drilling exploratory wells, hydrocarbon shows were found within Kalol formation in all drilled wells. While testing the objects identified based on wireline log data, oil and gas flowed in two wells. The identified reservoirs are less permeable and have thickness in the range of 2-4m as can be seen in the log (Figure-2). Appraisal or development of these sub-seismic reservoirs is a major challenge as to get areal extent of the reservoir is critical to estimate the hydrocarbon in place and placement of future appraisal and development wells.

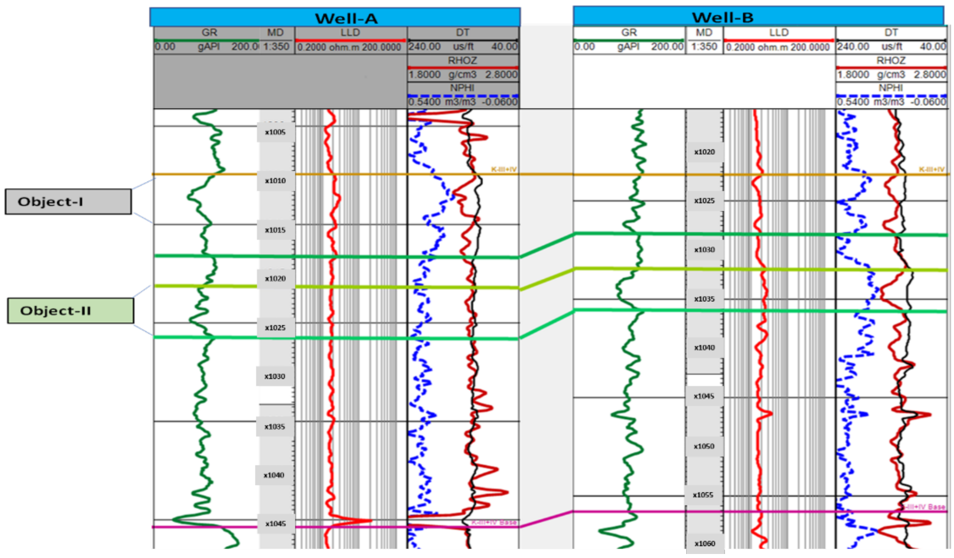


Figure-2: Log response against the zone of interest (reservoir thickness 2-4m)

Data sets

Pre-stack 3D seismic and data of six wells drilled in the block were used for the Inversion analysis. We used three angle stacks, Near, Mid & Far having angle range 10-18, 17-26 & 25-34 respectively). Final processed well log data has been used. Out of six exploratory wells (well-A, B, C, D, E & F) drilled in the study area , first two wells (wells A & B) have shear sonic log. We used Krief's equation to derive Shear sonic log using recorded compressional sonic log of respective wells.

Theory

Seismic inversion is the process of estimation of a subsurface impedance model from seismic data that is consistent with the geology. In other words, inversion uses the seismic data to determine the geology which caused that seismic response.

Seismic inversion technique is classified in to two types: Deterministic and Stochastic. Deterministic inversion is further divided into Post stack and Pre-stack inversion. Outputs of Pre-Stack inversion are elastic properties such as P-reflectivity, S reflectivity and Vp/Vs ratio. The deterministic inversion process produces one least-squares solution.

Limitations of deterministic Inversion
1. Seismic band limited: Seismic data is band limited, typically limited to about 10 Hz to 45 Hz, and therefore inversion may not be meaningful for thin bed reservoirs.
2. Non-uniqueness: Multiple geologic model may give same seismic response

Pre-Stack Simultaneous Inversion:

Pre-Stack inversion (Simultaneous Inversion) in Hampson-Russell is based on the assumption on a linear relationship between logarithm of P-impedance (Ip) with both S-impedance (Is) and Density holds good for background wet lithologies (Fatti et al. (1994)) . The final estimate of Ip, Is and density can be achieved by perturbing an initial model and minimizing the difference between the model response and recorded seismic.

Stochastic Inversion

Geo-statistical inversion is stochastic inversion where a priori elastic property model with a plausible geologically consistent bedding geometries is updated and is constrained by seismic. The algorithm is a conditional simulation, an extension of Sequential Gaussian Simulation (SGS). This stochastic inversion process creates multiple possible solutions, which then can be averaged to create a probable solution. This technique improves the vertical resolution by integrating the fine vertical sampling of the log data with the dense areal sampling of the seismic data to create detailed, high resolution elastic property (elastic impedance, density or velocity) models utilizing geostatistical techniques.

Stochastic inversion has been carried out using GeoSI software developed by TOTAL and CGG that combines Geostatistical inversion and a multivariate Bayesian approach (Buland and Omer H (2003). GeoSI is layered based approach that works in a fine stratigraphic grid having vertical thickness of about 1-2ms and lateral sampling in order of seismic bin size. It helps to incorporation the higher frequencies which are not there in the seismic bandwidth.

Deterministic vs. Geostatistical Inversion Results

We carried out both deterministic as well as Geostatistical inversion with the objective of resolving the thin pays in the inverted volumes especially P-impedance and Vp/Vs ratio. Statistical wavelet extracted from the near angle stack seismic volume with opposite polarity is used for seismic well tie. A good correlation is achieved between seismic & well within the zone of interest (interval 1000-1500m) as shown in Figure-3.

Methodology adopted:

Three wavelets were extracted, one for each angle stack volume (Near, Mid & Far) as shown in **Figure-4**.

Four Seismic horizons at the tops of geological markers (name mentioned here as M1, M2, M4, & M5) are used to generate initial low frequency P-Impedance, S-impedance and density model. The Low frequency initial P-impedance model was created using Kriging process. Initial model for S-impedance and density are also created using the respective transform. Thus, the initial models, three angle stacks and three wavelets corresponding to each angle stack are used for deterministic simultaneous inversion as well as stochastic inversion.

In GeoSI, this low frequency model again is re-gridded to fine layered stratigraphic grid having layer thickness of the order of 1-2ms. GeoSI generates multiple high frequency realizations and corresponding posterior uncertainty. This Posterior uncertainty increases with decreasing thickness of the layers. Adopted workflow is given in Figure-5.

Along with the seismic and well data as stated above, this inversion technique also uses horizontal and vertical variograms along with uncertainty.

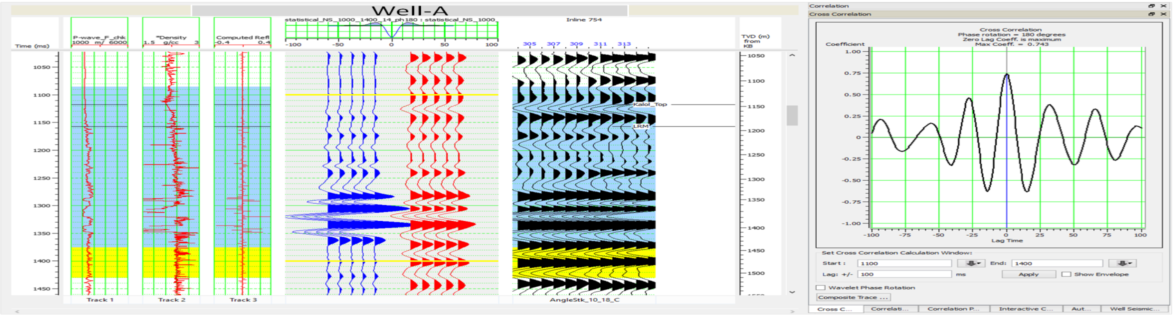


Figure-3: Seismic-well tie

Figure-4: Wavelets extracted (with phase 180 degree) for three angle stacks (Near, Mid & Far)

Work flow adopted for the Geostatistical inversion is as follow:

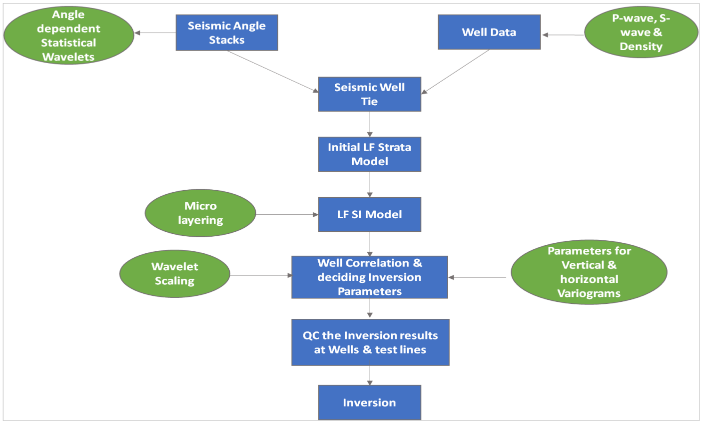
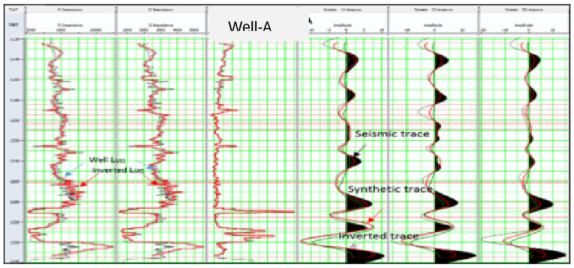


Figure-5: Workflow adopted for the stochastic inversion.

Prior to run the final inversion, we can optimize the inversion parameters by quality checking the intermediate inversion results at well location and through any section passing through wells or blind well testing (Figure-6).



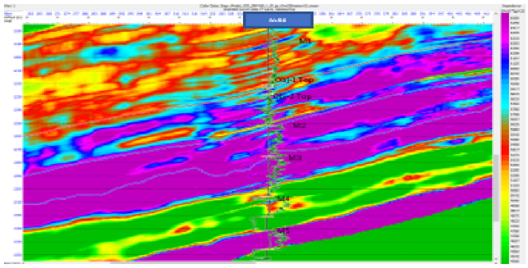


Figure-6: Results of inversion at well location (Well-A) and through a line passing through well-B for quality check purpose.

In stochastic inversion, the outputs are multiple realizations of Ip, Is and VpVs ratios. We have considered here the mean value of different realizations of P-impedance and Vp/Vs ratios only for result comparison.

Figures-7, 8, 9 & 10 show the comparison between final outputs of P-impedance derived from Deterministic and Stochastic inversion respectively. P-impedance and Vp/Vs ratio derived from GeoSI has a much closer match with the well P-impedance and Vp/Vs ratio.

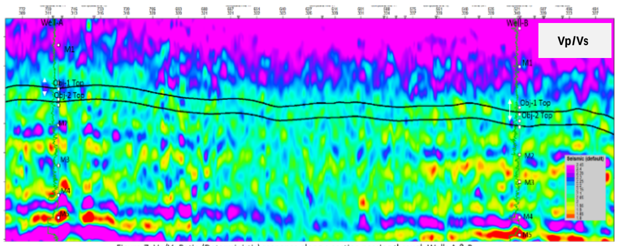


Figure-7: Vp/Vs Ratio (Deterministic) response along a section passing through Wells A & B.

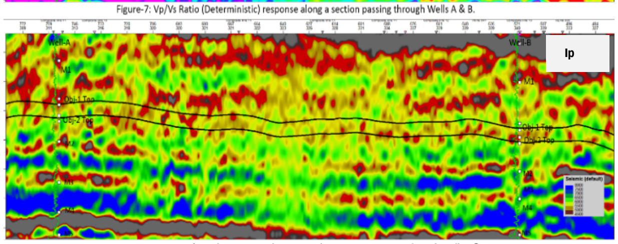


Figure-8: P-impedance (Deterministic) response along a section passing through Wells A & B.

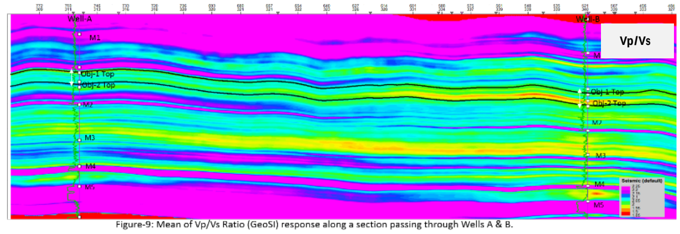


Figure-9: Mean of Vp/Vs Ratio (GeoSI) response along a section passing through Wells A & B.

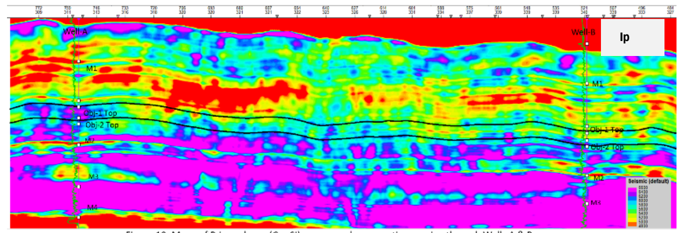


Figure-10: Mean of P-impedance (GeoSI) response along a section passing through Wells A & B.

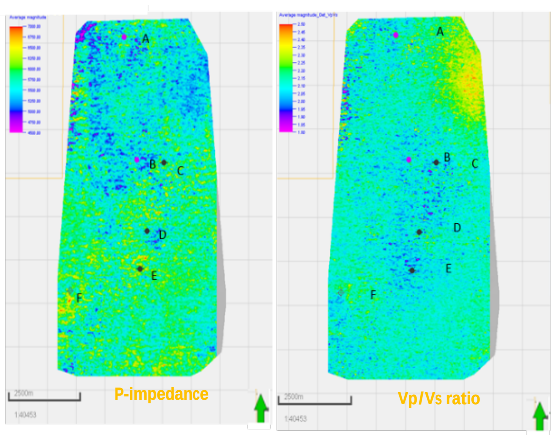


Figure-11: P-impedance and Vp/Vs ratio (Deterministic) between Obj-1 Top & Obj-2 Base.

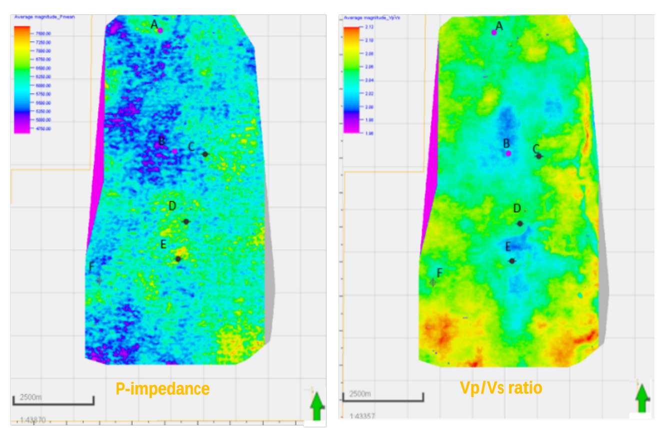


Figure-12: P-impedance mean and Vp/Vs ratio mean (GeoSI) between Obj-1 Top & Obj-2 Base.

Wells A and B have encountered sand reservoir thickness of 2-4m. The average value of P-impedance and Vp/Vs ratios derived for the interval between object-1 top and Object-2 base from deterministic inversion are shown in Figure-11. P-impedance and Vp/Vs ratio derived from stochastic inversion (GeoSI) provided a better resolution against the zone of interest (object-1 & 2) in stochastic inversion which can be interpreted with higher confidence (Figures-12).

Conclusion

In the present study, the application of Stochastic inversion helped to delineate the thin reservoir. The areal extent of reservoir can be mapped with more confidence and also it reduces the uncertainty.

As the seismic inversion does not provide a unique result i.e. there is not a single solution to the given problem, several derived models may equally match the same seismic response results need to be used with some constraint. The inversion results significantly contribute in de-risking and optimization of appraisal/ development well locations in an area, when used in combination with other data.

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