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Integrated Seismic Interpretation of the Mumbai High Field

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Summary

We present a case study of integrated seismic interpretation of a large heterogeneous carbonate field. The seismic interpretation is developed in a stepwise approach, first on amplitude data and then on inversion data for achieving high level of accuracy and consistency in the final structure. This method is applied in order to overcome typical signal ambiguities and wavelet instability encountered across the field. Both relative (RAI) and absolute acoustic impedance (AAI) derived from post-stack inversion are successively used to refine the interpretation as AAI provides a clearer image of the reservoir and fault compartments. Eventually, fault interpretation is fine tuned on edge enhancement attributes. The final time interpretation is then depth converted via an integrated velocity model based on geostatistical velocity modeling preserving seismic inversion well ties.

Introduction

The Mumbai High field is a brown field located 160km WNW off Mumbai city in India. The field consists in a doubly plunging asymmetric anticlinal structure with a gentle western limb located on a basement high. The eastern limb of this structure is affected by a set of major down-to-coast faults. The field strtucture is dominated by major fault systems i.e. the N-S Dharwar and SE-NW Satpura trends. The sedimentary sequence is of Tertiary age and most productive reservoirs of the field are within the Miocene carbonate L-II and L-III units. Mumbai High field is covered by a 3D seismic survey acquired in 1997 and reprocessed as PSDM in 2005 representing 1750 sq. km of full fold data. This study presents a revisit of the structural interpretation of the field as part of an extensive full field review and infill development plan.

The main challenges in Mumbai High field are reservoir heterogeneity and excessive gas production from the large gas cap. Reservoir heterogeneity has complicated the understanding of the water front within the reservoirs making it difficult to locate bypassed oil and optimally distribute water injection for efficient flooding. To provide foundations for the reservoir characterization and compartmentalization analysis, this paper focuses on the structural mapping and velocity modeling methodology.

Objectives

The main objective of this integrated interpretation is to generate a robust and geologically consistent structural interpretation. It includes both horizon mapping of L-II and L-III top reservoirs, and fault interpretation for proper compartmentalization analysis. For modeling purpose, the interpretation has to be depth converted consistently with seismic inversion attributes using a 3D velocity model in order to be accurately integrated later in the geocellular model for property modeling.

Methodology

The top reservoir horizons are initially mapped on PSDM 3D seismic amplitude data and then refined on relative acoustic impedance (RAI) on SAWE volume (Spatial Adaptative Wavelet Estimation) by snapping the horizon picks to the zero-crossing of the RAI volume. This procedure is followed to ensure that the top limestone reservoir is accurately picked. Then, further fine tuning is done on absolute acoustic impedance data obtained from seismic post-stack inversion. This workflow is devised to benefit from the clearer signature of the reservoir in acoustic domain than in amplitude domain and to benefit

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from the higher resolution of inversion data. The seismic inversion data facilitates the mapping of both top reservoir horizons and faults with much higher confidence in areas where the PSDM amplitude data is ambiguous, contaminated with noise, wavelet instability and/or phase ambiguity.

At the completion of the time structural interpretation, an integrated velocity model is built using available well TDR, well ties used in the inversion and seismic velocity. First an exploratory velocity data analysis is carried in order to select relevant data, identify velocity field trends and establish the degree of seismic to well velocity calibration. In addition, variogram analysis enables to capture both the basin trend and geological layer based anisotropy variation in the velocity model. The method for velocity modeling follows a two step approach where 14 wells with original VSP data are used with seismic velocity. This model helps generating TDR for 56 wells used for inversion. Secondly, the refined TRDs from inversion well tie are fed back into the velocity model.

The velocity modeling methodology is based on geostatistical universal kriging (kriging with external drift). The exploratory data analysis shows that a linear estimator for velocity is appropriate. Hence, kriging is chosen over moving average (MA) and functional interpolation (FI), as kriging provides a best linear unbiased estimate. In this context, 'best' means that error of estimation is lower on average than other linear estimators and 'unbiased' means that the expected value of the kriged estimate is equal to the true location at each location. Kriging offers another advantage over MA and FI schemes as it not only

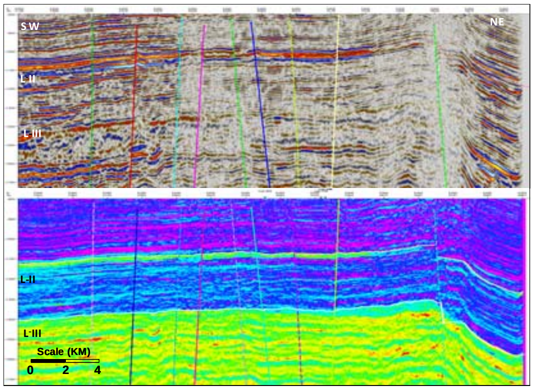

Figure 1: Seismic cross-section comparing amplitude data versus acoustic impedance data for structural interpretation.

incorporates the major/minor trend of data, but also limits the estimation of value at a location by limiting the operator within specified ranges and choice between the global and local mean. Another key observation in the exploratory data analysis is to accommodate an external drift factor in order to successfully enable the propagation of the velocity field. Universal kriging offers the same as kriging with external drift/trend.

One of the assumptions made in kriging is that the data being estimated are stationary. Whenever there is significant spatial trend in the data values such as sloping surfaces or depositional trends in a basin, this assumption is violated. In such cases, the stationary condition can be temporarily imposed on the data by use of a drift term. The drift is a simple polynomial function that models the average value of the scatter points. The residual is the difference between the drift and the actual values of the scatter points. Since the residuals should be stationary, kriging is performed on the residuals and the interpolated residuals are added to the drift to compute the estimated values.

Results

The new structural interpretation is coherent, shows a geologically consistent pattern and maintains the fault density over the field. Seismic inversion (AAI) provides the best data support for refining the top L-II and top L-III horizon over the field and enables to generate a much more reliable identification of the top reservoir units (Figure 1). Seismic inversion data (RAI and AAI) overlaid with well log AI are key in firming up the well ties to guide the horizon picks and remove ambiguities inherited from amplitude data such as areas contaminated with noise, or phase/polarity ambiguities across the field (Figure 2). The analysis of the acoustic impedance data also helped refining the shale out boundary identified at L-II level towards SE (Figure 3).

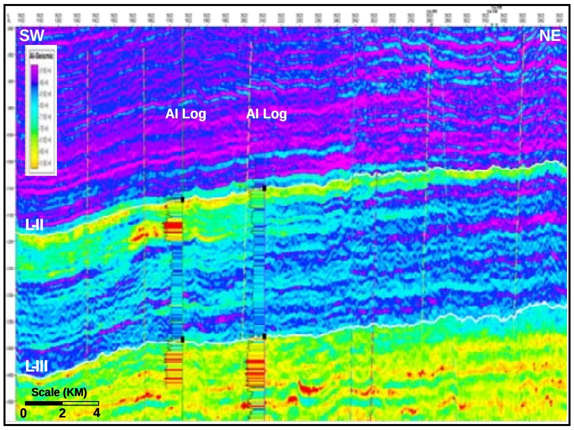

Figure 2: Seismic cross-section showing the acoustic impedance overlaid with well log AI.

For fault interpretation, the seismic inversion data (AAI) provides a clearer image and more confidence in locating and adjusting the faults that were ambiguous on amplitude data (Figure 1). This interpretation approach is coupled with further validation from edge enhancement attributes (Variance^{TM}) generated on band limited data (low pass filter). The interpretation is focused on systematically delimiting horst and graben structures. This is done to maintain a structurally consistent framework.

Snapping of the interpretation on the RAI and validation on AAI, does not only provides more confidence in the top reservoir picks, but also enables more precision than amplitude data thanks to the higher resolution obtained in the AAI domain. This translates in the end by consistent and reduced time residuals, better tie in time domain and a better match in depth domain after depth conversion.

Analysis of the velocity modeling raw results suggests that this approach provides a robust model with depth residuals of less than 2m standard deviation at both L-II and L-III on 150 blind wells (Figure 4). For the validation and analysis of velocity model results, a detailed QC is performed including IJK model direction to ensure absence of bull's eyes and anomalous velocity zones in the final velocity field modeling. In addition, preserving the inversion well ties in the velocity model enables the use of inversion data during subsequent reservoir property modeling.

Conclusions

Because of the relatively good acoustic contrast at the top L-II and L-III reservoir, the acoustic impedance inversion data facilitates picking of the top reservoir horizons in areas where PSDM amplitude data is noisy or ambiguous. Fault interpretation also benefits from interpretation on acoustic inversion data, which provides a clearer image of the fault blocks, and from the edge detection attribute analysis.

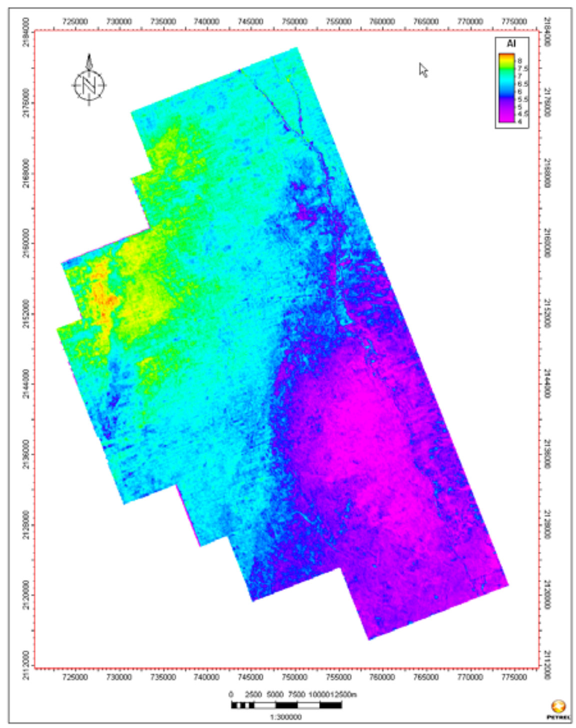

Figure 3: Instantaneous attribute map of acoustic impedance at L-II reservoir showing shale out towards SE.

Snapping of the horizon interpretation on RAI data enables more accurate mapping in time thanks to higher resolution of RAI data than amplitude domain data.

This translates in better tie with geological well markers at top L-II and L-III levels and eventually a better match in depth domain after depth conversion. The final horizon and fault interpretation is coherent and uniform and shows a geologically consistent structural pattern across the field.

The geostatistical velocity model enables to integrate all relevant velocity data, to capture velocity basin trends and velocity anisotropy and to depth convert in a consistent way both interpretation and seismic inversion volumes. Eventually, depth converted interpretation and seismic inversion are used to construct the structural and property model and help capturing reservoir heterogeneity to reduce uncertainties during the ongoing infill well drilling campaigns.

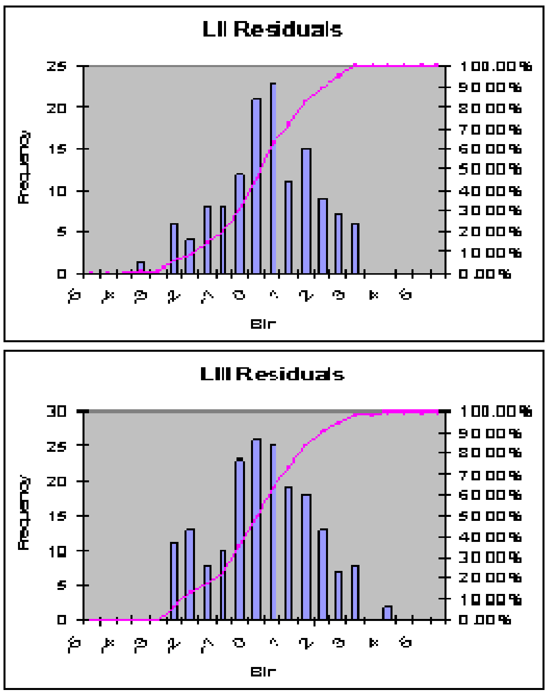

Figure 4: Depth residuals in meters from velocity modeling prior to final depth match.

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Statement from Author

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