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Reservoir Grade 3D Seismic: Quality Issues for Quantitative Reservoir Characterization - The Case Study of Mumbai High

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Summary

Mumbai High, a mature field in the Indian Western Offshore has been producing hydrocarbons for over thirty five years. The production from this field peaked during late 1980's to early 1990's. Massive redevelopment programs have been launched in phases since 2000-2001 with the objective to improve oil production and maximize recovery. In a bid to sustain and improve recovery from the ageing field, it is necessary to identify areas of by-passed oil through various state of the art and emerging technologies. Maximizing knowledge extraction from the available 3D seismic data is one such important effort towards achieving this goal.

Quantitative estimation of reservoir properties and identification of locales of the by-passed oil can be done through suitable inversion techniques on 3D seismic data calibrated with direct measurements in bore holes which leads to a reliable geological model for bringing out sub- layers' geometry, lithology, porosity and fluid saturation. Keeping this objective in view, the relative amplitudes preserved anisotropic Pre-Stack Time Migration (PSTM) seismic data of Mumbai High calibrated with well data was used to generate a high resolution geological model and property volumes of L-II and L-III reservoirs in depth domain in the Mumbai High Field.

The 3D seismic data of 1997-98 vintage was reprocessed in 2005. The data shows good match with drilling results, in general, as far as the structural aspects are concerned. However, rigorous quality checks and well to seismic ties revealed interesting insights in the 3D seismic data and it is observed that the data in some parts has quality issues which may lead to higher uncertainties in reservoir characterisation in certain regions. This paper deals quality issues in 3D seismic data which may cause inaccuracies in the predictions and steps required to improve data acquisition and processing for a more meaningful interpretation and successful reservoir characterisation.

Introduction

Mumbai High is a mature field and has been producing hydrocarbons since 1976. The production from this field peaked during late 1980's to early 1990's and then started declining. Massive redevelopment programs have been launched in phases since 2000-2001 with the objective to improve oil production and maximize recovery. This involved re-interpretation and integration of all available data and preparation of an upgraded reservoir model followed by in-fill drilling. These efforts resulted in not only arresting the decline but envisaging a higher recovery also. This turn around could be achieved through concerted efforts involving huge capital and technological inputs.

A lot of initiatives have been taken to make use of the latest technologies in Mumbai High. The main objectives in Mumbai High, like in any other field, are to maximise recovery and quantify additional producible reserves. As a first step in this direction it is imperative to sustain and improve production from the ageing field through various state of the art and emerging technologies. In this endeavor, Seismic data plays an important role in identifying locales for additional in-fill drilling and deciding the

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trajectories of horizontal wells to target bypassed oil. Seismic data can also significantly contribute by quantitative analysis of various reservoir properties. This paper deals with the methodology adopted for the study, quality issues in seismic data which enhanced uncertainties and the lessons learnt for future data acquisition & processing campaigns for a more meaningful interpretation and successful reservoir characterisation.

Objectives

The seismic reservoir characterization analysis is based on seismic inversion and rock physics, which led to geological model building and property estimations.

The main objective of the seismic inversion and rock physics analysis is to support reservoir characterization and quantitative interpretation to derive reservoir and overburden properties from surface seismic. The quantitative seismic reservoir characterization aims at providing:

- Continuous data for static model building and flow simulation.
- Support of infill well target selection process.
- Risk analysis for new wells

In this approach, rock physics is the key enabling technology that links seismic properties to reservoir properties.

Methodology

This analysis is based on combining pre-stack seismic inversion and rock physics modeling. As such, the work scope was subdivided into 5 steps:

1 The initial data preparatory work for facilitating the pre-stack inversion. It includes data editing for all available vertical wells with measured elastic properties (compressional and shear velocity, density) and shear velocity prediction for the vertical well which have only compressional velocity measurement.

2. Well data analysis for establishing the rock physics model that describes the relationship between the elastic properties such as bulk modulus and shear modulus, density and reservoir properties like porosity, saturation and volume of clay.

3. Seismic pre-stack inversion: the inversion workflow was designed to maximize the resolution by broadening the bandwidth and correcting the seismic wavelet to zero phase. It also aimed at obtaining high resolution seismic acoustic impedance from broad band zero phase data. The primary objective of this phase was to generate an acoustic impedance volume from the 3D seismic volume (PSDM) of sufficiently good quality such that reservoir properties derived from it (i.e., Phi-t) could be successfully used to populate the reservoir static model.

4. Stochastic rock simulation from the rock physics model and calculation of elastic properties form the stochastically simulated properties (porosity, Vclay, saturation).

5. Generation of litho-cube and joint stochastic inversion for prediction of reservoir properties with associated probabilities.

The method is based on a complete Bayesian approach that integrates different measurements at different scale. The advantage of this approach is to ensure consistency between properties, here porosity and volume of clay prediction, by running a joint estimation of both properties together using a rock physics model. The stochastic simulation and Bayesian estimation theory enable to address the multi-scales effect between log domain and seismic domain and to capture associated uncertainties. The volume of clay/porosity inversion is based on rock-physics relationships and well-log calibration. The stochastic simulation addresses the uncertainty of the elastic / stiffness relationship for a given reservoir property pair (porosity/Vclay) and vice- versa.

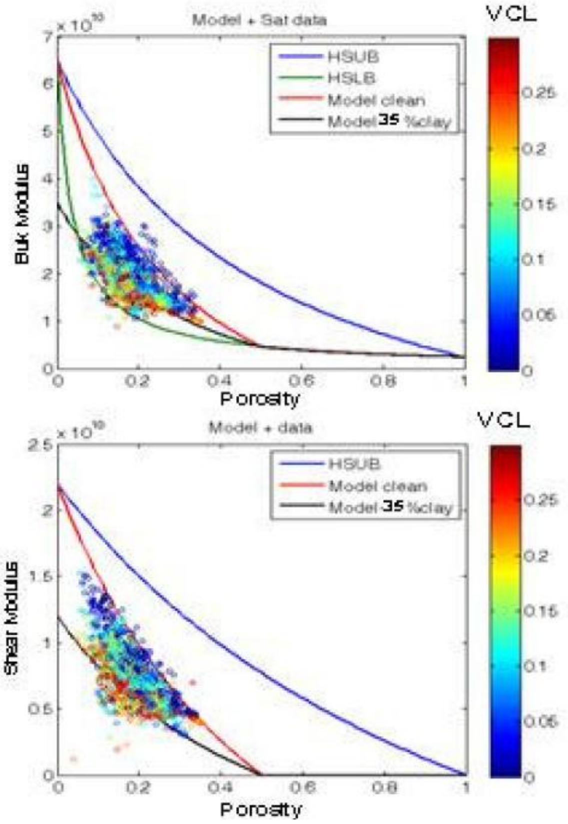

Fig. 1: Modified Hashin–Shtrickman model jointly predict boundary of the data for bulk (top) and shear (bottom) moduli versus porosity.

Seismic Data Quality Analysis

1. Seismic Data lacks AVO response

The PSTM gathers contain noise and therefore, it was difficult to assess whether the seismic data is responding to expected fluid and lithology changes or not. A synthetic gather generated from conditioned well logs at well location SN-511 shows AVA effects associated with fluid in L-III carbonate.

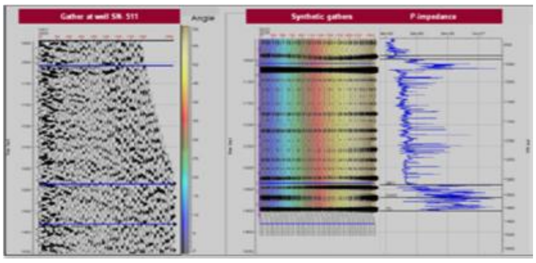

Fig.2 : PSTM gather, Synthetic gather and well log.

2. Acquisition Footprints in Seismic Data

A representative time slice showing striping in seismic data (an acquisition artifact). The uneven signal strength affected the calibration of well to seismic data. Well locations are falling mostly in poorer RMS amplitude zones thus adding uncertainties in calibration of seismic data.

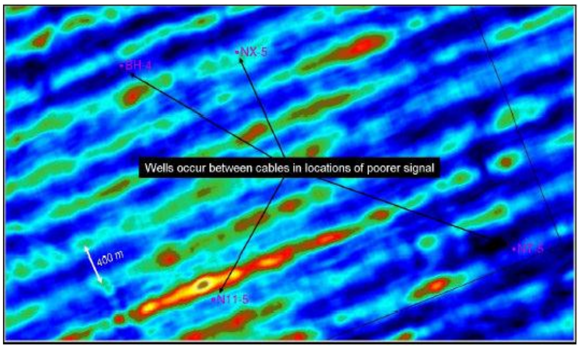

Fig.3 : Time slice from RMS Amplitude volume showing strong acquisition foot-prints responsible for uncertain well to seismic tie.

3. PSTM in-fill Artifacts

PSTM filled the low fold areas leaving migration smiles which extend in the zone of interest. The well locations occur in the zone of data loss.

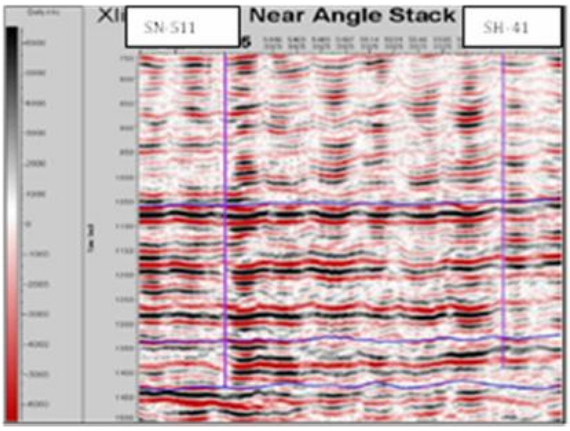

Fig.4 : Vertical section showing periodic amplitude fluctuation due to acquisition foot-prints resulting in migration smiles in low fold areas.

4. Seismic Data Contained Multiples

A comparison of synthetic, near angle seismic, synthetic with multiples and P-Impedance data of well SN-511 is shown below. The extra events seen in near angle seismic data are interpreted to be the multiples.

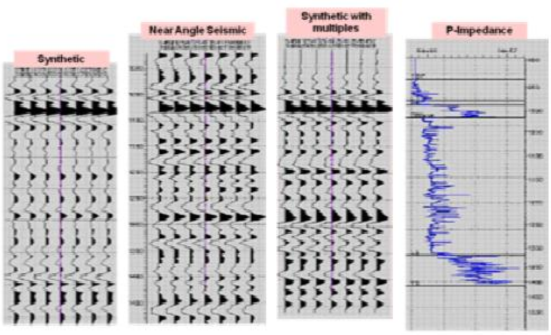

Fig 5 : Data has multiples in the zone of interest which could not be removed effectively resulting in uncertainties in quantitative reservoir characterization.

Results

The exploratory rock physics analysis shows that clay content within the reservoir has strong effect on moduli-porosity trends for both bulk and shear data (Figure 1). The rock model reproduces main aspect of reservoir properties; porosity trends with respect to clay content. Rock physics analysis also suggests that clay content is more significant than saturation effects. The seismic pre-stack inversion was run on the PSDM 3D data over the 1750 sq. km covering the full Mumbai High Field. Though the general quality of the seismic gathers is not optimum for AVO inversion, fair to good quality P-Impedance and Poisson's ratio (PR) were obtained via extensive data preconditioning of the input gathers.

Subsequent reservoir characterization is performed by combining the inverted P- Impedance and PR with the rock physics model through Bayesian joint stochastic inversion, which resulted in good porosity and volume of clay prediction throughout the field.

As part of the analysis of the results, a full validation exercise is conducted separately both qualitatively and quantitatively. From a qualitative standpoint, visual comparison of petrophysically derived and joint inversion predicted porosity and volume of clay for all wells used in the inversion shows good

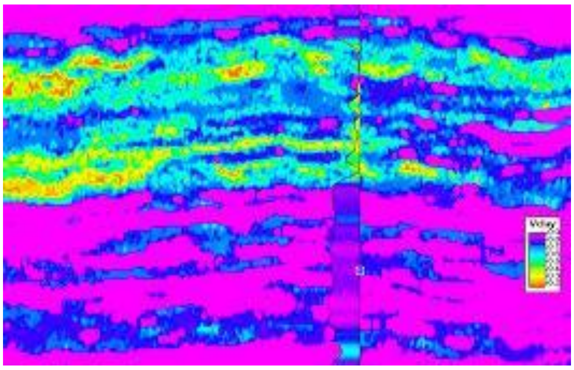

Figure 6: Jointly inverted Vclay Maximum A Posteriori Probability overlaid with Vclay log at well location.

tie (Figure 6). Correlation coefficient analysis (R2) is conducted on blind wells between porosity and volume of clay curves from the wells and the seismic elastic derived porosity and volume of clay outputs. The correlation analysis is taken as a measure of the quality of the joint stochastic inversion results.

Conclusions

Rock physics analysis shows that clay content within reservoir has strong effect on moduli- porosity trends both for bulk and shear data in Mumbai High field. Rock model reproduces main aspect of reservoir properties; porosity trends with respect to clay content. However, saturation effects are found within range of model uncertainty i.e. masked by the model uncertainty, and clay content is more significant than saturation effects. Contribution of small variation in V_{clay} is higher than saturation changes.

Bayesian joint stochastic inversion results in very good porosity and volume of clay and prediction correlate with well measured property. Correlation coefficients are around 70% (R2) for V_{clay} and around 60% (R2) for porosity for both L-III and L-II reservoirs.

Finally, the joint inversion results are used for static reservoir property modelling of the field. However, drilling results may show surprises due to limitations in the seismic data quality. The following conclusions can be drawn regarding quality issues which should be taken care while acquiring and processing seismic data for quantitative reservoir characterisation:

- The 3D seismic data should be acquired with no / minimal acquisition footprints.
- Presence of multiples in the zone of interest ultimately proved detrimental in the present case. Therefore, at the time of data processing adequate removal of all multiples particularly in the zone of interest is to be ensured as the left over multiples will always be present in the impedance inverted volume and add to the uncertainty in reservoir characterisation.
- Lower frequency band (all recordable frequencies less than 10 Hz) of the seismic signal should also be preserved for improved resolution and for building a reliable trend model to reduce uncertainties.

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Statement from Author

The data used in this paper is the property of Oil and Natural Gas Corporation Ltd. Views expressed are of the various experts and the author and; do not necessarily reflect the official views of ONGC.