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Mumbai High Field Heterogeneity Addressed Through Quantitative Seismic Reservoir Characterization

S. Dasgupta*, S. Volterrani*, R. Bachrach*, A. Carrillat*, S. Sharma*, N. Dutta*, M. Pratap**, R Bhanja**, A. Saha**, and T. Friedel*, **Schlumberger DCS ** ONGC Ltd.*

Summary

We present a case study of heterogeneous carbonate reservoir characterization conducted via quantitative seismic reservoir analysis of pre-stack inversion with rock physics modelling and Bayesian joint stochastic inversion. The jointly predicted porosity and volume of clay are then used as input for static reservoir modeling.

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. The sedimentary sequence is of Tertiary age and most productive reservoirs of the field are within the Miocene carbonate LII and LIII units. 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. Reservoir heterogeneity arises from the variation in porosity/permeability in the carbonate layers affected by changes in clay content and marked diagenetic overprint and dissolution. This study focuses on reservoir heterogeneity mapping from quantitative seismic reservoir characterization. The analysis is based on pre-stack inversion and rock physics modeling.

Objectives

This seismic reservoir characterization analysis is based on seismic inversion data and rock physics, which is part of larger study covering static and dynamic full field modeling.

The main objective of the seismic inversion and rock physics analysis is to support reservoir characterization and quantitative interpretation using continuous seismic data 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 with only compressional velocity measurement.
2. Well data analysis for establishing the rock physics model. Rock physics model 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

Data and Consulting Services , Schlumberger Asia Services Limited, NSE Estate, Western Express Highway, Goregaon(E), Mumbai-400067, India, SDasgupta@bombay.oilfield.slb.com

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 depth migrated seismic volume (PSDM) of sufficiently good quality such that reservoir properties derived from it (i.e., Phit) 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. It uses Bayesian classification techniques (Sengupta and Bachrach, 2007) for generating the probability density functions (PDFs) associated with different lithology. The advantage of this approach, compared to other classical inversion methods, 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 pair) and vice-versa (Bachrach, 2006).

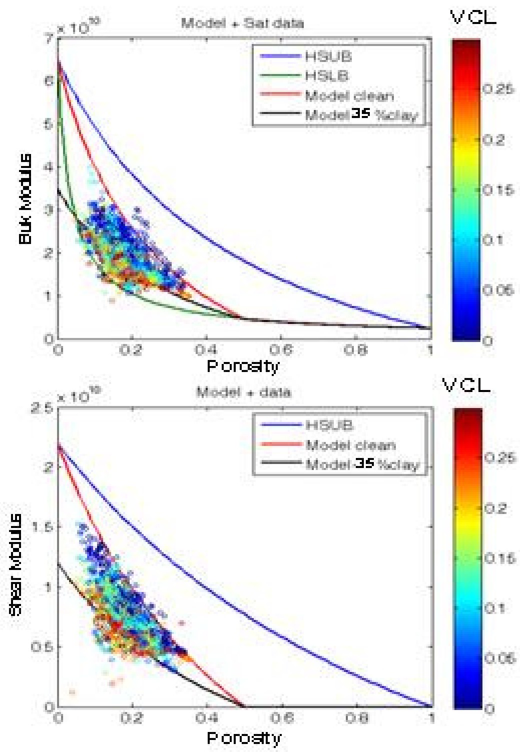

Figure 1: Modified Hashin–Shtrickman model jointly predict boundary of the data for bulk (top) and shear (bottom) moduli versus porosity.

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 field area. Though the general quality of the seismic gathers is not optimum for AVO inversion, good quality P Impedance and PR (Poisson's ratio) 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 results 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

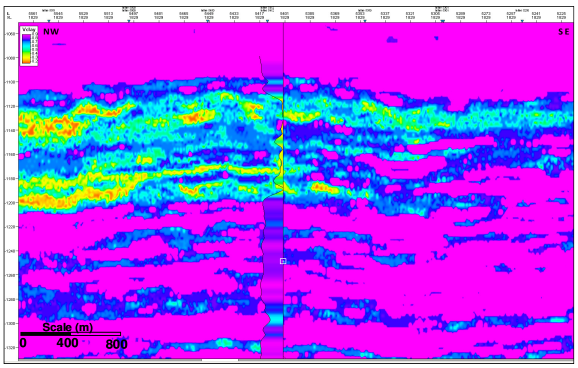

Figure 2: Jointly inverted Vclay Maximum A Posteriori Probability overlaid with Vclay log at well location

the inversion shows good tie (Figure 2). 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 Vclay 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 above 71% (R2) for Vclay and above 62% (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 that is used to guide ongoing infill well drilling campaigns.

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Statement from Author

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