Integrated probabilistic petrophysical and rock physics approach for reservoir characterization and fluid identification- A case study

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Complex lithology, VpVs ratio, Aspect ratio, Inclusion, Fluid identification, Reservoir Characterization

Summary

Petrophysical volumes are one of the key inputs for any physical Rock Physics modelling workflow. Rock Physics cross plot trends play an important role in Lithology and fluid indentification/ discrimination. Realistic estimations of these petrophysical volumes (mineral volumes, porosity and fluid saturations) become quite important in complex lithology formations, e.g., Panna formation, in Bombay Offshore field in India, since these petrophysical volumes drive the Rock Physics trends for each lithology. Bombay Offshore field, in India, comprises of three producing formations, each with different relative percentages of calcite, quartz, dolomite and clay. Since, each mineral has a different elastic property its relative percentage in a rock affects the elastic response differently.

Iterative and integrated multi-mineral petrophysics and rock physics modelling workflow has been employed in this study. Output volumes from multi-mineral petrophysics are used as input for rock physics modelling to generate elastic logs (density, P-Sonic and S-Sonic). Rock Physics Model, in turn, helps to constrain these petrophysical volumes. Any discrepancy in the relative mineral volumes from petrophysics reflects with inconsistency in predicted rock physics trends. This workflow served as a good quality control for petrophysical evaluation. Finally, using these petrophysical volumes, rock physics modelling was done to generate elastic logs which were further validated by blind well test followed by well-to-seismic tie which yielded more confidence on the effectiveness of this integrated workflow. Hence is is evident that integration of rock physics cross plot analysis, probabilistic petrophysical evaluation assisted by rock physics fluid model gave better and realistic elastic log responses after rock physics modelling.

Introduction

Rock Physics Modeling is a well-known technique to predict compressional, shear wave velocities and bulk density of a formation. These elastic wave properties and bulk density are derived from the reservoir parameters like water saturation, porosity and mineral volumes which are estimated from well log data. A realistic rock physics model establishes a link between elastic properties and reservoir parameters of the rock. Therefore, multi-mineral petrophysical evaluation guided by rock physics, plays an important role in complex lithology formations.
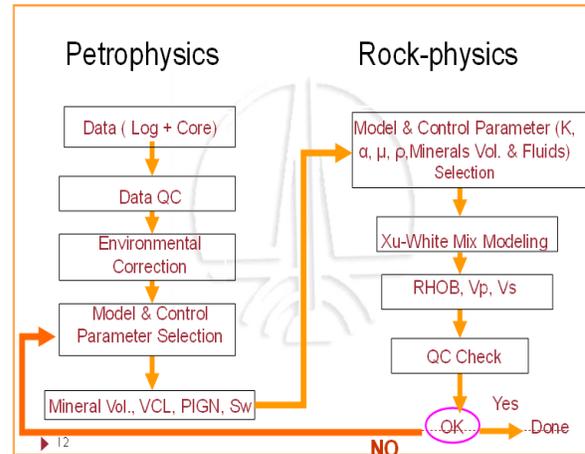
Integrated probabilistic approach of petrophysics and rock physics for reservoir characterization and fluid identification.

In this study, an attempt was made to develop a realistic rock physics model in complex sandstone lithology formation of Paleocene age and Limestone lithology formation of Mid Eocene to Oligocene age of Bombay Offshore field situated to the west of Indian Peninsula. Three major producing formations i) Panna, a sandstone regime ii) Bassein and iii) Mukta, carbonate regime were considered for rock physics modeling for reservoir characterization. Panna formation is composed of sand, silt, coal, shale and limestone streaks overlain by Bassein and Mukta formation which are composed of limestone and dolomite.

Since, Well-A was the only well with both compressional and shear log, it was selected as the reference well for rock physics modeling. Later, the same rock physics model was used for predicting elastic logs in other wells. These predicted logs from the wells, will be further incorporated into pre-stack seismic inversion studies.

Multi-mineral petrophysical evaluation played a major role in building realistic rock physics model, which could give an effective lead do reservoir characterization in complex lithology formations.

Figure 1: Integrated workflow of petrophysics and rockphysics

Method

An integrated approach was adopted to do Petrophysical analysis and Rock Physics Modelling Fig.1. Multi-mineral petrophysical interpretation has been carried out to estimate the realistic reservoir parameters (porosity and water saturation) and petrophysical volumes (quartz, calcite, clay and coal) in these formations. Inclusion-based rock physics model (Keys and Xu, 2002) was used to predict elastic logs in Panna formation whereas, another inclusion-based model (Xu and Payne, 2009) was used to predict in Bassein and Mukta carbonate formation. Rock Physics Model built on Well-A (parametric well) was applied to Well-B (blind well) in which no shear log was available but good quality P-Sonic log was present to validate the results. For further validation, well-to- seismic tie was done on Well-B. The synthetic seismic with predicted log shows a very good cross correlation with observed seismic data with the value of correlation coefficient 0.91 which is higher than the case with recorded log.

Petrophysical Modelling

Multi-well crossplot analysis of Density-Neutron, Density-P-Sonic (DT) and Density-S-Sonic (DTSM) was done to identify different lithologies making use of both core and cutting data. A stochastic multi-mineral approach for petrophysical evaluation (Fig-2) has been adopted to estimate the reservoir parameters (viz total porosity, effective porosity, water saturation) and mineral volumes like clay, quartz, calcite and coal volume for the Panna and calcite and dolomite volume for Bassein and Mukta formation. The conditioned well logs (Gamma ray, Resistivity, Density and Neutron) were used as input to estimate mineral volumes. The outputs (total porosity, total water saturation, volume of clay, quartz, calcite, and dolomite) obtained from petrophysical evaluation served as input parameters for rock physics modeling. In event of any inconsistency observed with generated rock physics trends after rock physics modeling, the petrophysical model was further refined to generate optimum volumetrics.

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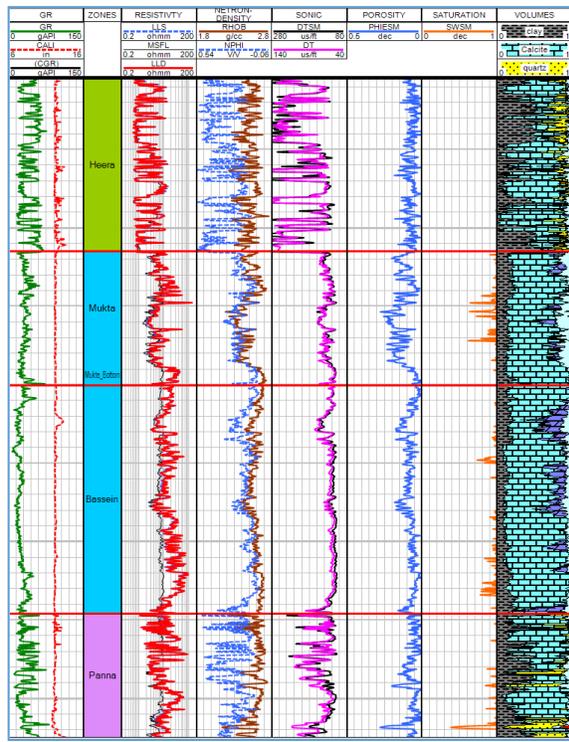

Figure 2: Petrophysical output of Well-A. Track 2 shows the lithology Clastic zone (in pink) has sandstone alongwith limestone and shale. Bassein and Mukta (in blue) zone is limestone and Heera (in green) is shale with limestone streaks.

Rock Physics Modelling

Rock Physics Modeling has been widely used as an effective tool for elastic logs prediction in a formation. However, for a meaningful application, rock physics modeling should be guided accurately with geological constrains (Mathur, 2018), in terms of mineral volumes as well as rock architecture. The response of seismic waves over a formation is a function of elastic properties, viz. compressional velocity, shear velocity and density of the formation. The seismic wave response is also dependent on the reservoir properties like porosity, water saturation, volumes of fluids, shape of pores (aspect ratio) etc. In this study, the inclusion model proposed by Keys and Xu (2002) was selected to compute the elastic

properties for calcareous sand, shaly sand as a function of porosity, mineral modulus and pore aspect ratio whereas, Xu and Payne model (Xu and Payne, 2009) was selected to compute the elastic properties of limestone and dolomitic limestone. The site specific rock physics model was developed on Well-A which poses good quality conventional logs, a complete set of sonic logs (DT and DTSM), ancillary parameters (pressure and Temperature etc.). Mineral specific pore aspect ratio for clean matrix (α=0.12) and clay (α=0.045) were used for developing the rock physics model. For Bassein and Mukta carbonate formation, fractions of secondary porosity with their respective aspect ratios has been incorporated in the rock physics model. Reuss-Voigt Hill Average method was used to mix the dry framework minerals and Brie fluid mixing model (Brie et al., 1995) was used to mix the saturating fluids. This parameterized rock physics model was applied on Well-B as blind well test to check for its match with P-Sonic log only since S-Sonic log was absent in this well. Logplots in figure 3 shows good match of the rock physics modeled density, compressional, shear velocity (in red) with the recorded density, compressional and shear velocity (in black). Figure 3a shows cross-plot (P-impedance, versus Vp/Vs ratio) of recorded and predicted data for Well-A. Figure 3b and 3c shows cross plot (P-impedance, versus Vp/Vs ratio) with lithofacies on Z-axis for both Well-A and Well- B. Different lithology trends are evident from above figures. The outputs from the standard petrophysical method when used for rock physics modeling could not separate the lithology trends on the elastic logs, whereas it is clearly separated after iterative petrophysics and rock physics modeling workflow. Facies like calcite, hydrocarbon bearing clastic points, brine bearing clastic points are clearly separated. This provided confidence to predict the P-Sonic and S- Sonic logs in other wells where shear log was not available. The application of integrated and iterative multi-mineral petrophysics and rock physics modeling workflow shows clear rock physics facies trend.

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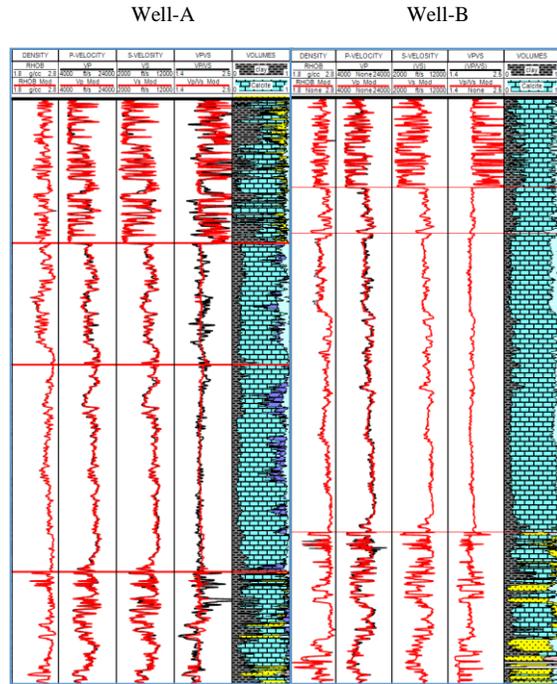
Well-A   Well-B

Figure3: Petrophysical output of Well-A and Well-B along with P-velocity, Vp and S-Velocity, Vs. (Recorded and predicted logs are shown in black and red respectively.

Shale	Brine SST	Oil SST	Gas SST	LST* (Tight)	Brine LST

Figure 3d: Lithofacies description.
*SST- Sandstone
*LST-Limestone

Well to seismic tie

The elastic log predicted in Well-B from integrated multi-mineral petrophysics and rock physics modeling workflow was validated with well to seismic tie (Figure 4).
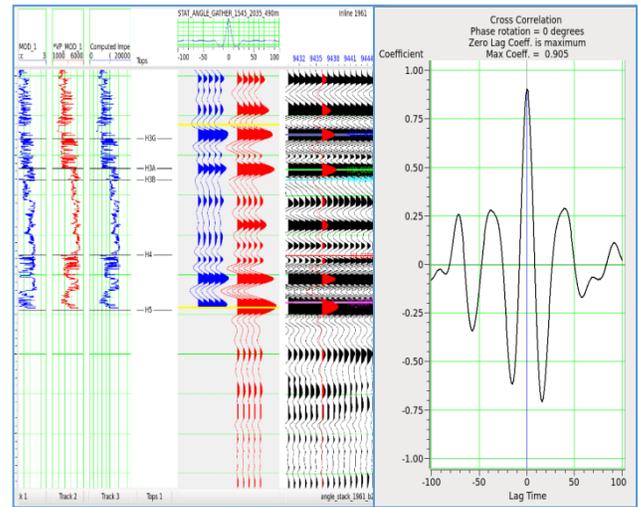
The correlation coefficient of synthetic seismic data generated with predicted log data was improved to 0.91. Furthermore, AVO modeling on the well-B will be carried out to assess the prediction of the shear sonic log from rock physics modeling.

Conclusions

This study emphasized the importance of multi-min

Figure 4: Synthetic seismic with modelled log (Blue) generated on Well-B shows cross correlation of 0.91.

petrophysics integration with rock physics modeling in complex lithology formation. Multi-mineral approach for petrophysical evaluation played crucial role in building realistic and consistent rock physics model, which characterizes the correct lithology

Well-A   Well-A   Well-B
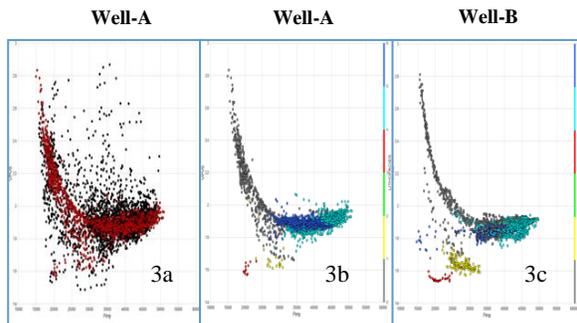

3a   3b   3c

Figure (3a): Cross-plot generated between Pimp vs Vp/Vs ratio for recorded data of well-A. Figure (3b): Cross-plot generated between Pimp vs Vp/Vs ratio for modelled data of well-A. Figure (3c): Cross-plot generated between Pimp vs Vp/Vs ratio for predicted data in Well-B with Lithofacies

trend. In absence of realistic estimation of different mineral volumes, correct rock physics trends cannot be built. The predicted P and S- Sonic log in blind wells gave us more confidence on developed rock physics model. Petrophysics and rock physics integration is of great importance in any rock physics study.

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