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GEO India 2022

# Integrated and iterative petrophysics and rock physics workflow application - an implication for reservoir characterization in carbonates, Western Offshore Basin, India

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## Abstract

Rock Physics is the study of sensitivity of seismic waves to rock properties like porosity, pore shape and volume of minerals present in that particular rock. The fractional volume of minerals and pores present in rock can be estimated through petrophysical evaluation. Use of well logs excellently assist to estimate porosity, water saturation and clay volume. Realistic estimation of these properties is very important for prediction of compressional and shear wave velocity using rock physics modelling workflow. Rock Physics modelling is a link between petrophysics and rock physics. Integrated and Iterative approach provide an excellent way for doing realistic petrophysics as well as acoustic wave velocity prediction. In this study, integrated and iterative application of petrophysics and rock physics workflow has been discussed with case study to get the correct fraction volumes of minerals, porosity and water saturation along with correct computation of sonic wave velocity and bulk density in carbonate formation. Rock Physics modelling helped to identify facies trend viz gas, oil, water and shale. Based on Pimpedance versus Vp/Vs ratio crossplot gas bearing limestone having Pimpedance and Vp/Vs ratio in the range of 22000-35000 g/cc*ft/sec and 1.7-1.8 respectively in Bassein formation is clearly discriminated from oil and water bearing limestone.

## Introduction:

The study area WO-16 (Fig-1) is situated in the Western Offshore Basin, on the western margin of India. So far Total 13 nos of wells have been drilled in this structure. Depending on the data quality and spatial distribution of wells total 7 wells out of 13 wells were selected for petrophysical evaluation and Rock Physics Modelling in Bassein, Mukta Heera and Panvel fromations. Shear and Compressional log data are the necessary input for building a Rock Physics Model. The RPM model is always build and validated with the recorded shear and compressional log data. Good quality Shear log is available in 3 wells. Remaining 4 wells did not have shear logs and selected for prediction of shear, compressional and density logs using Rock Physics Modelling. Well-A, Well-B and Well-C have shear logs where as Well-D and Well-E did not have shear logs. Well-A was selected for Rock Physics Model building and Well-B and well-C were selected for Model Validation. Well-D and well-E were used as blind well for prediction of RHOB, DTCO and DTSM. Based on the developed Rock Physics Model shear logs were predicted in Bassein, Mukta, Heera formations in remaining wells.

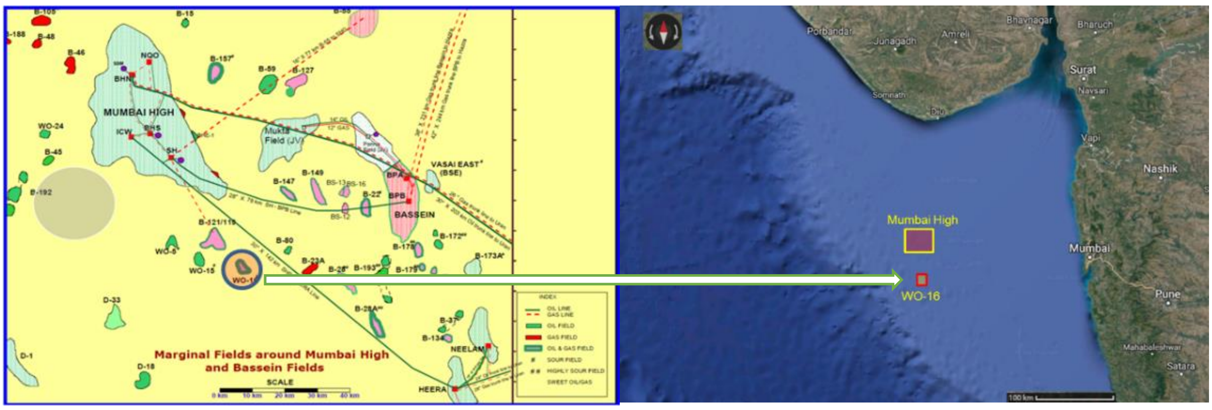


Fig- 1: Location map of Study area

## Stratigraphy of the area:

The sedimentation in the area has taken up on basaltic or granitic / metamorphic basement. The deposition of Paleocene to Early Eocene clastics and equivalent carbonates of Panna Formation took place unconformably over the Basement. The Middle to Late Eocene Bassein Formation was deposited unconformably over the Panna Formation. The Bassein Formation is overlain by Early Oligocene Mukta Formation. This formation is gas-bearing in WO-16 structure and other structures nearby. During Oligocene period, wide variation of facies has been observed in this area. Mukta Formation is overlain by Panvel Formation of Late Oligocene age and is consisting of mainly limestone with intermittent shale and claystone layers. Panvel Formation is succeeded unconformably by Early to Middle Miocene carbonate sequence of Bombay & Bandra Formation. End of Middle Miocene marks the drowning of the DCS platform and the deposition of Chinchini. The generalized stratigraphy is given in Figure-2.

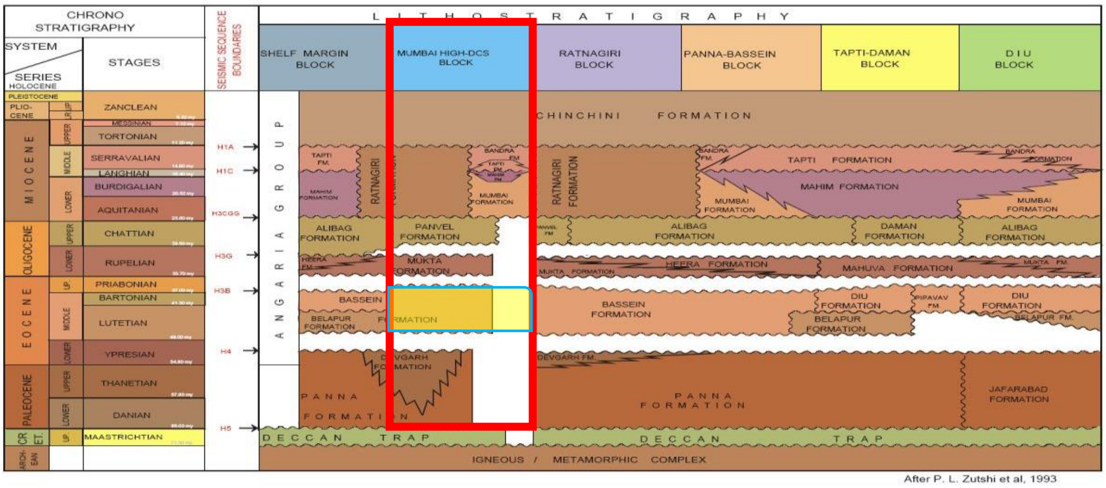


Fig- 2: Generalised Stratigraphy of the area

## Methodology:

In this study the following integrated and iterative Petrophysics and Rock physics workflow (Fig-3) was applied for computation of reservoir properties and prediction of elastic logs.

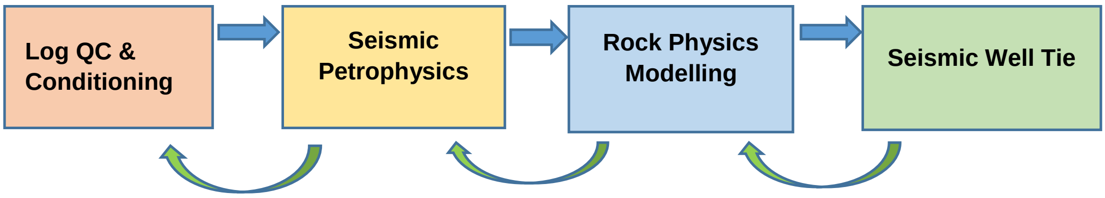


Fig-3: Integrated and Iterative workflow

Log QC and conditioning process involves depth matching, washout correction and normalization of the logs. The conditioned logs are then used as input in seismic petrophysics process for computation of volumetrics of minerals, porosity and fluid saturation. The volumetrics of minerals, porosity and fluid saturation resulted from seismic petrophysics are then used in rock physics modelling by integrating all the data. The correlation coefficient achieved between recorded and predicted elastic logs suggest the re computation of reservoir parameters by iterating the parameters in seismic petrophysics (Akash Mathur, Geo India 2018). Finally the predicted in situ elastic and density logs were used for seismic to well tie by generating synthetic seismogram. The low correlation coefficient between seismic to well, suggest for revisit of rock physics modelling. Good seismic to well correlation coefficient finalizes the model whereas low correlation coefficient involves iteration for rock physics modelling.

## **Well Log data QC and Conditioning**:

Well Log data QC were done by generating histograms and cross plots of Density(RHOB) vs Compressional Velocity(Vp), Pimpedance (Pimp) vs Vp/Vs (Compressional to Shear Velocity) ratio. Conditioning of well logs is the first step to bring all the log in a state of environmentally corrected, accurately depth matched and free from any data gaps. Logs are affected by rugose and enlarged boreholes and data gaps are occurred at places where during log data acquisition padded devices is to be closed to avoid tool stuckups. In this study Multi linear Regression techniques and Machine Learning techniques were used to generate synthetic logs to fill the data gaps, environmental corrections were applied and any depth mismatched were corrected with respect to resistivity logs.

## Seismic Petrophysics:

Seismic Petrophysics is the process to compute the realistic reservoir parameters like porosity, water saturation and clay volume of the formation. Multiwell Ƶ plot (Fig-4) of neutron density log data were generated to identify the lithology alongwith core/cutting study (Fig-3A, 3B & BC). A stochastic multimineral approach for petrophysical evaluation has been adopted to estimate the reservoir parameters (viz total porosity, effective porosity, water saturation) and mineral volumes like clay, calcite and dolomite volume for Bassein Mukta and Heera formations. The conditioned well logs (Gamma ray, Resistivity, Density and Neutron) were taken as input along with core and mud log data to estimate mineral volumes. The outputs (Fig-5) (total porosity, effective porosity, water saturation, clay, calcite, and dolomite volumes) obtained from petrophysical evaluation served as input parameters for Rock Physics Modelling.

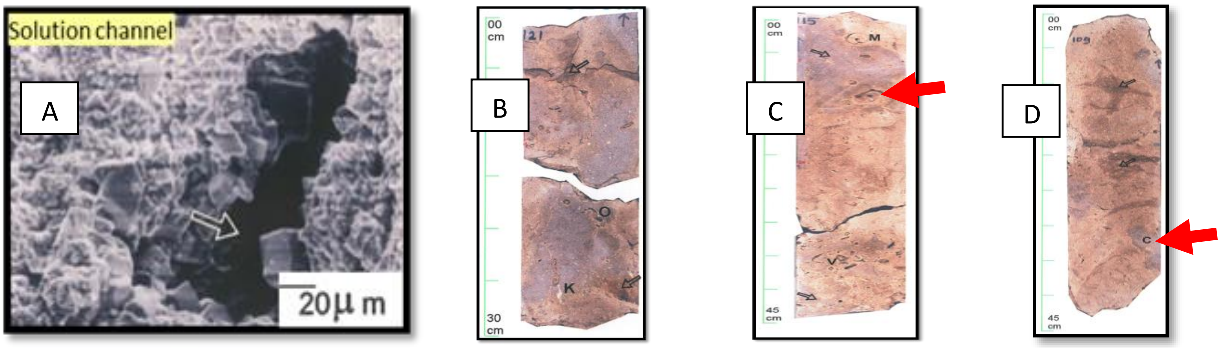


Fig-3A: SEM image of Upper Bassein limestone in well-C, depicts the solution channel as Partial spartitisation of micritic matrix has reduced primary intergranular. **Fig-3B**: Packstone facies. solution pores and organic porosity (O).Secondary kaolinite fills within tension gashes/fractures. **Fig-3C**: The facies displays moldic porosity (M). Solution pores/Vugs (V) and channels are observed in the lower portion. **Fig-3D**: The facies exhibits light brown residual accumulation of brown argillaceous matter due to solution invasion.

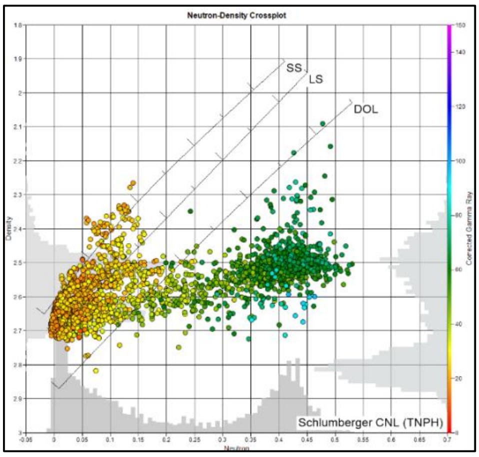


Fig-4: Neutron Density crossplot for Lithlogy identification in well-A.

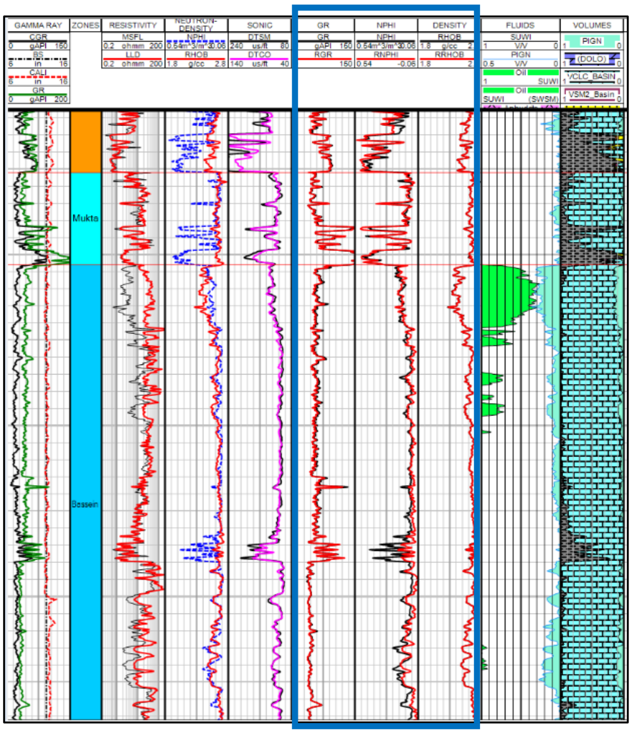


Fig-5: Log plot of well-A the blue rectangle portion shows the log tracks of reconstructed curves. A good overlays between recorded black and reconstructed red curve represents accuracy of petrophysical evaluation.

## Rock Physics Modelling:

Inclusion based Rock Physics modelling (Shiyu Xu2 and Roy E. White2, Geophysical Prospecting, 1996) is a well-known technique to predict a realistic elastic logs like compressional transit time (DTCO) and shear transit time (DTSM) and bulk density (RHOB) of the sandstone formation. The Xu Payne model is the Rock Physics Modelling method for carbonate formation which includes interparticle, moldic and fracture types of porosities (SHIYU XU and MICHAEL A. PAYNE, ExxonMobil, The Leading Edge, January 2009). The response of seismic waves is the function of elastic properties in terms of compressional velocity, shear velocity and density of the formation. The response of seismic waves is also dependent on the reservoir properties like porosity, water saturation, volumes of fluids, shape of pores (aspect ratio) (Kumar and Han, SEG 2005 Expanded Abstracts), effective pressure etc. Carbonates (Limestone and Dolomite) have three types of porosities viz interparticle, moldic and fracture porosity. The quantity of each porosity and their pore aspect ratios along with volume of clay and calcite and calcitic dolomite minerals control the elastic velocity (Eberli et al., *TLE*, 2003).

In this study an inclusion based Xu-Payne model (Xu Payne 2009) was selected to compute the elastic properties of limestone and dolomitic limestone. The site specific Rock Physics model was developed on well-D (Fig-5) which has good quality convectional logs, a complete set of sonic logs (DT and DTSM), ancillary parameters (pressure and Temperature etc.) using mineral specific pore aspect ratio for limestone having interparticle pores ($\alpha$=0.12), moldic pores ($\alpha$=0.8), fractures ($\alpha$=0.017) and clay ($\alpha$=0.045). An iterative approach was adopted to quantify the porosities in terms of primary, secondary and fracture porosity. Mixing of the dry frame work minerals were done using Voigt-Reuss Hill Average method and mixing of fluids were done using Brie fluid mixing model with exponential coefficient of "3". Differential Effective Medium method was used to include the pores in the dry framework. An iterative approach was adopted for fixing fractional volume of interparticle, stiff and fracture porosities to compute the shear and compressional velocities. Core study suggests both stiff as well as interparticle porosity in the formation and accordingly the volume of stiff, interparticle and fracture porosities were included in the model. Gaussman fluid substitution equation was used to substitute the fluids into the pores and finally the elastic properties were predicted using Xu_Payne method in well-A (Fig-6). Based on Pimp vs Vp/Vs crossplot (Fig-6A) having lithofacies on z axis, it is observed that recorded logs in well-A could not reveal the lithology trend whereas modelled logs (Fig-6B) very well separate each lithology.

This parameterized Rock Physics model was applied on well-D (Fig-7) in which shear log was not available. The modelled density, compressional velocity, shear velocity logs (in red plotted in 3$^{rd}$, 4$^{th}$and 5$^{th}$ track respectively) have good match with the recorded compressional and shear logs (in black). This resulted in providing confidence to predict the shear sonic log in other wells where shear log was not available. Thus the application of integrated and iterative petrophysical and rock physics modelling workflow shows clear lithofacies trend.

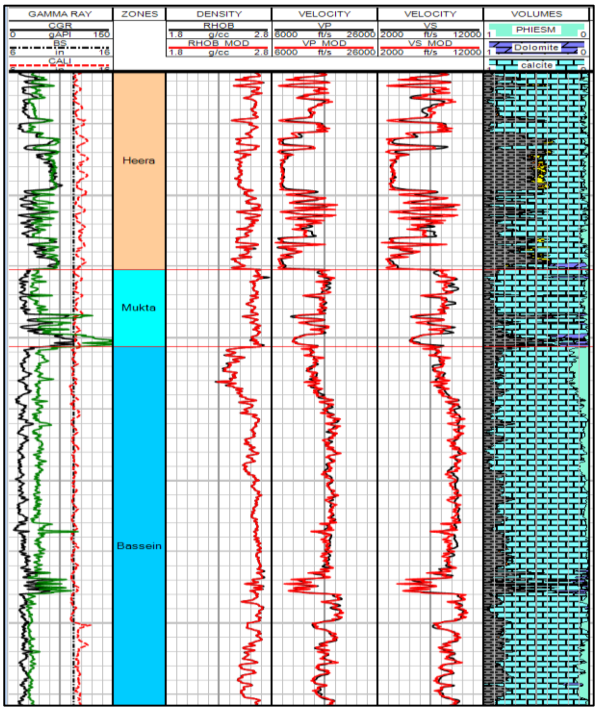


Fig 6: Log plot of model **well-A** where Density, P-Velocity & S-Velocity curves plotted in track-3,4 & 5 respectively. Recorded curve black and modelled curve red shows good match.

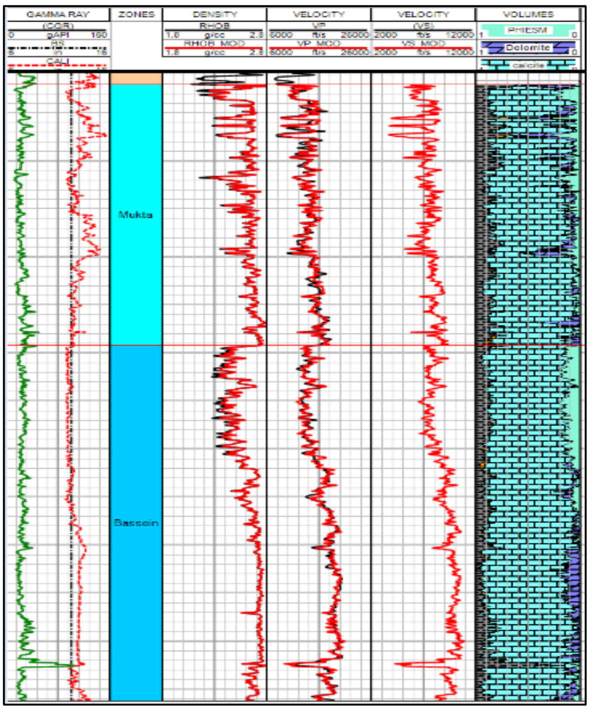


Fig 7: Log plot of blind **well-D** where Density, P-Velocity & S-Velocity curves plotted in track-3, 4 & 5 respectively. Recorded curve black and modelled curve red shows good match.

The Pimp versus Vp/Vs crossplot (Fig-6A, Fig-6B and Fig-6C) having lithofacies on z axis were generated to get the lithology trend. It is clearly evident from cross plots (Fig-6A) that the standard raw logs could not separate the lithology whereas it is clearly separated in cross plot (Fig-6B & Fig-6C) generated using rock physics modelled curves. The Pimpedance vs Vp/Vs ratio crossplot (Fig-6C) with elastic velocities predicted in blind well-D where shear log was not available shows Lithofacies (see lithofacies colour description) like tight limestone, hydrocarbon bearing limestone points, brine bearing limestone points and shale points are clearly separated.

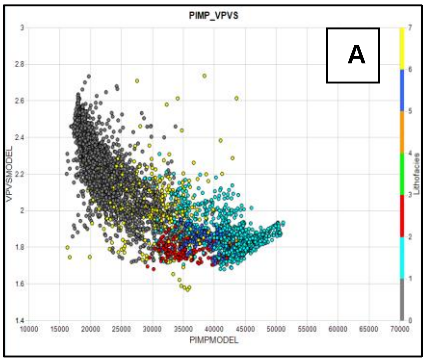


Fig -6A: Pimp vs Vp/Vs cross plot of raw logs in well-A (Model well)

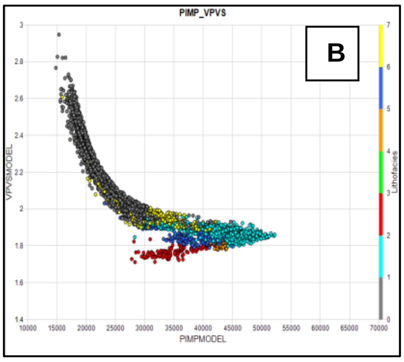


Fig -6B: Pimp vs Vp/Vs cross plot of modelled logs in well-A

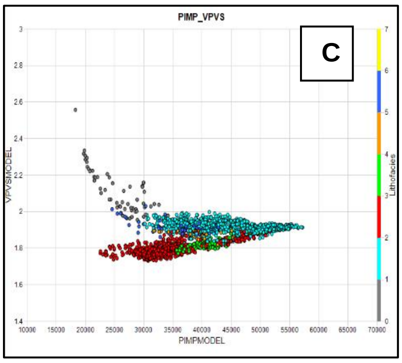


Fig -6C: Pimp vs Vp/Vs cross plot of predicted logs in well-D (Blind well)

## Lithofacies colour description:

| Clay | Tight Limestone | Gas | Oil | Marginal Oil | Water limestone | Argillaceous Limestone |
|---|---|---|---|---|---|---|
| | | | | | | |

## Well To Seismic Tie:

The modelled elastic logs obtained from integrated and iterative petrophysics and rock physics modelling were validated with well to seismic tie (Fig-7). The pink colour is the synthetic seismic generated using predicted elastic log shown in red rectangle portion in figure 7. The correlation coefficient of 0.88 was achieved by creating synthetic seismic data using predicted log against the synthetic seismic data generated using raw log data. The improvements resulted in better seismic inversion study.

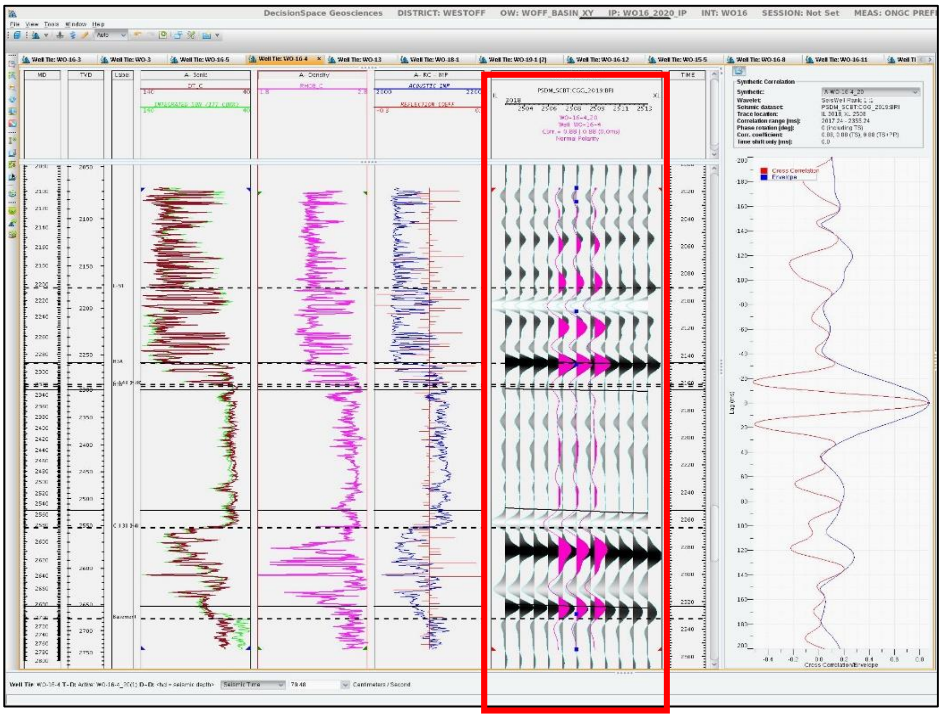

Fig -7: Well to seismic tie having correlation coefficient of 0.88 in well-B.

## Conclusion:

This study emphasize the importance of integrated and iterative Petrophysics and Rock physics modelling application. The developed rock physics model applied on remaining five wells for elastic log prediction and it is found that lithofacies trend viz gas, oil, water and shale can be clearly discriminated from the oil and water bearing limestone on the basis of Pimpedance versus Vp/Vs ratio. However in the recorded data, lithology trend do not infer any significant meaning due to the mixing of all the facies. For gas bearing limestone Pimpedance is in the range of 22000-35000 g/cc*ft/sec and Vp/Vs ratio is in the range of 1.7-1.8. The Oil bearing limestone could not be separated from water bearing limestone because Vp/Vs ratio and Pimpedance of both the facies are in the same range i.e. Vp/Vs ratio from 1.8-1.9 and Pimpedance from 34000-45000 g/cc*ft/s. The predicted elastic logs were used in inversion study for reservoir characterization.

## Acknowledgement:

Authors are very much thankful to ED – Mr Vishal Shastri, Head of the Institute, GEOPIC, ONGC, Dehradun for providing technical input and guidance for writing this paper. Thanks are due to GGM-Mr Nandan Verma, Head-INTEG, GEOPIC, Dehradun, India for providing all kind of support for this work. We thank ONGC management for allowing us to submit this paper in Geo-India 2022, 5th South Asian Geosciences conference and exhibition.
The views expressed in this paper are solely of the authors and do not reflect the view of ONGC.

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