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Role of Data Analysis in fixing parameters for petrophysics & rockphysics modeling for effective seismic reservoir characterization–A case study

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Summary

The data which is recorded close to the reservoir by the measuring devices i.e. Well Log data and reservoir data play a vital role for understanding the reservoir and its behavior. The detail data analysis will lead to conceptual model for defining the reservoir properties through petrophysical modeling. The objective of the petrophysical interpretation is to transform well log measurements into reservoir properties i.e. porosity, saturation, permeability, mineral component volumes etc. These parameters are responsible for oil/gas estimation and production sustainability. Rock-physics transform petrophysical results into elastic properties that can be linked to seismic interpretation. This complementary nature of Petrophysics and Rock physics requires a tight integration for seismic reservoir characterization. Well log data and its analysis from various angles plays a crucial role in this process of integration. During drilling process log data are affected by borehole rugosity, invasion, mud cake formation, salinity, temperature & pressure etc. and sometimes logs could be entirely missing or not usable due to bad hole conditions. Thus log data needs to be conditioned before its evaluation. In general, most of the times petrophysical evaluation, petro-elastic modeling and synthetic to seismic tie are done independent of each other. This introduces uncertainty and inconsistency across the geoscientific data. Ideally, Petrophysics and Rock physics modeling should be an integrated process that can produce a greater consistency among different data. This paper highlights detail data analysis by various technique to firm up the rock model for petrophysical evaluation, rock physics modeling and the scenario modeling as applied in the study of a gas field in deep water offshore basin of ONGC, India.

Key Words: *Data Analysis, Log conditioning, Petrophysics, Rock-physics, Petro-elastic modeling, Seismic reservoir characterization*

Introduction

The study area, is an offshore part of Mahanadi basin, is bounded in the southwest by 85 degree East Ridge whereas its structural separation with adjacent Bengal Basin is apparent by a deep throw of NW-SE trending fault. The major part of the present block encompasses the northeastern part of the Mahanadi basin. Bathymetry in the block varies from 800m to 2100m and the contours run more or less in northeast-southwest direction.Fig.-1

Well log data provides a continuous record of a formation rock properties and its analysis helps in understanding the characteristics of reservoir. Petrophysical interpretation in turn provides a way to arrive at accurate values for the hydrocarbon saturation, movable and immovable hydrocarbon, water saturation, porosity, permeability and the lithology.

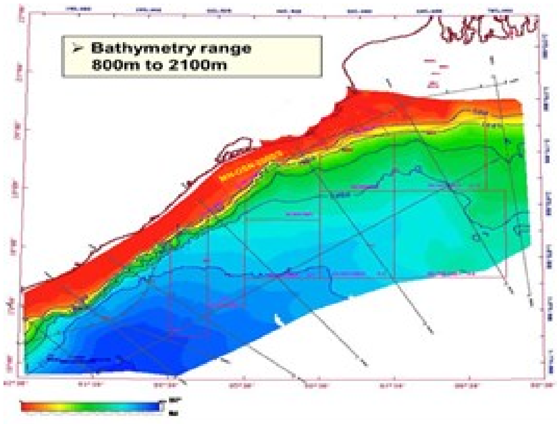

Fig-1: Location Map

For accurate determination of reservoir parameters in terms of petrophysical output (volume of shale & minerals, porosity and saturation) for any rock, identification of its constituents is of utmost importance. Knowledge of matrix

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mineral, clay minerals and other mineral if present is beneficial to unravel complex reservoir and to arrive at more accurate petrophysical properties.

The common problems faced by interpreter are the data sets of different service companies with different tool and vintage. Sometimes the wells are drilled with different drilling fluids and also it is possible that data could not be recorded in the zone of interest due to bad hole condition. To overcome these situations the data from the different sources need to be rescaled, normalized, synthesized and edited for erroneous values. This process is known as log conditioning. The data is then depth matched and corrected for the environmental effects.

Data Analysis for Mineral Identification for Petrophysical Analysis

The data after conditioning is now ready for the analysis. Crossplots are a convenient way to demonstrate how various combinations of logs respond to lithology and porosity. They also provide visual insight into the type of mixtures. Neutron porosity and density Crossplot is one of the strongest combination for identification of different lithology with fluid on linear scales with water-saturated pure lithologies (Sandstone, limestone, dolomite lines) graduated in porosity units. When the matrix lithology is a binary mixture (e.g., sandstone-lime or lime-dolomite or sandstone-dolomite) the point plotted from the log readings will fall between the corresponding lithology lines. Fig-2

Once the lithology has been identified and confirmed with the available core data, petrophysical analysis can be made.

This requires selection of parameters to be used in the interpretation model for processing. The basic parameters which are applied throughout the interval covering different formations under study are the Temperature at the depth of computation (obtained from the surface and bottom hole temperatures), Mud density, Resistivity of mud, mud filtrate and mud cake (recorded in laboratory during drilling), Formation water salinity/ resistivity from Rt VS Phi Crossplot (Picket plot), Hydrocarbon type and its density from testing.

The Petrophysical parameters a, m, n which are responsible for saturation estimation are generally obtained from laboratory. The selection of water saturation equation depends upon the various situations of hydrocarbon accumulation and type of rock & its properties.

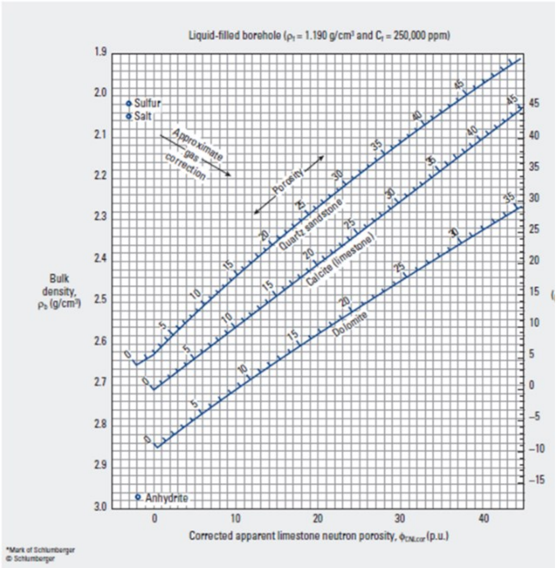


Fig-2: N-D Crossplot for lithology identification

Petrophysical Analysis

Although there are various techniques for processing but most widely used are deterministic and probabilistic approach. Now a days the latest technique for multimineral model is an Inverse optimisation technique which is adopted by almost all the oil companies. This technique also accounts for tool uncertainty and relative curve weightage with all the geological constraint for that formation.

For any rock, petrophysical interpretation provides volume of minerals and shale, the porosity (both total and effective) and the hydrocarbon volume (movable and immovable). In order to carryout seismic reservoir characterisation we need to link petrophysical results i.e., the reservoir properties to the properties measured in seismic ,i.e. elastic properties , through rock physics modeling.

Data Analysis for Rockphysics modelling

The elastic properties (Vp, Vs, RHOB) depend upon a number of reservoir properties like Facies, Fluids, Porosity, Saturation, Pressure, Stress, Temperature, etc. They depend most on the microstructure or the fabric or texture of the rock. Porosity plays an important role. Also the shape of the pores and the number and nature of the grain contacts affect the elastic properties of the rock. A Change in anyone of the reservoir properties e.g., shale content will lead to change in porosity. Thus the texture of the rock, and hence the reservoir properties, is created and controlled by depositional, sedimentological and diagenetic processes. The correct interpretation requires quantifying the connection between geology and seismic data. Rock physics models that relate velocity and impedance to porosity, saturation and mineralogy (e.g. minerals and shale volume, fluid content) form a critical part of seismic analysis.

Elastic moduli is one of the key parameter for velocity estimation which is influenced by different factors of sedimentation process but falls within some permissible limits called bounds depending on porosity.Fig-3

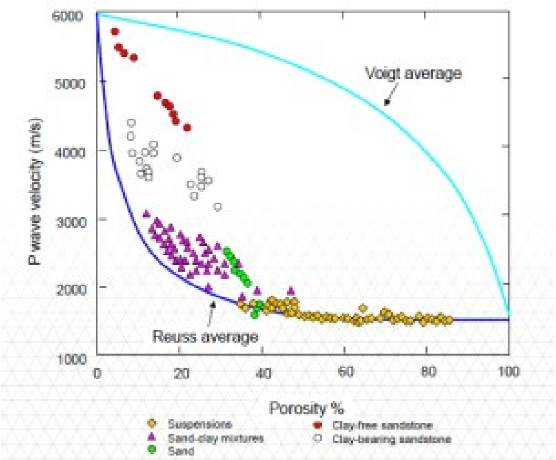


Fig-3: Upper and lower Elastic Bounds

The upper and lower bounds of the elastic moduli of rocks provide a useful framework for velocity–porosity relations. Theoretically the effective elastic moduli of rocks and sediments have been described through different “effective-medium” models. The “inclusion based models” approximate the rock as an elastic block of mineral perturbed by holes, while the “granular-medium models” or “contact models” describe the behavior of the separate elastic grains in contact. Whatsoever be the approach, the model should specify the volume fractions of the various constituents, the elastic moduli of the various phases, and the geometric details of how the phases are arranged relative to each other.

Fig-3 shows that before deposition, sediments exist as particles suspended in water (or air) and so their acoustic properties fall on the Reuss average of mineral and fluid. As the sediments deposit on the water bottom, their properties fall on (or near) the Reuss average, as long as they are weak and unconsolidated. Their porosity position along the Reuss average is determined by the geometry of the particle packing. Clean, well-sorted sands will be deposited with porosities around 40%. Poorly sorted sands (like sand-clay mixture and clay bearing sandstone –Fig3) will be deposited along the Reuss average at lower porosities. Chalks will be deposited at high initial porosities. Upon burial, the various processes that give the sediment strength – effective stress, compaction, and cementing – move the sediments off the Reuss bound. It is observed that with increasing digenesis, the rock properties fall along steep trajectories that extend upward from the Reuss bound at critical porosity, toward the mineral end point at zero porosity.

This analysis is essentially required for selecting suitable model and providing appropriate values of aspect ratio, compaction factor, effective bulk modulus(K) and shear modulus(μ) for estimation of elastic logs.

Rockphysics Modeling :

The objective of the rock physics modelling is to provide link between the petrophysical properties and the elastic properties of the rock (Vp, Vs and RHOB).This link will allow the elastic properties of the rock determined through seismic inversion to be interpreted in terms of reservoir properties.

Rockphysics makes use of the mineral and fluid volumes from petrophysics processed output. The total porosity and saturation are also obtained from log data processing. The Petrophysical analysis helps to identify the reservoir with fluid and the non–reservoir. Selection of bulk and shear modulli is done according to the matrix reflected in the lithology crossplots. The Voigt and Reuss bounds help us to select the aspect ratio value for both the matrix and clay and the Effective Elastic modulli of the formation suitable for the model to estimateVp and Vs.

Petrophysical Modelling of Well A:

A critical part of establishing a predictive and consistent rock physics model is the generation of high quality and consistent petrophysical properties. The stratigraphic sequence encountered in Well#A has been subdivided into various litho units, with reference to their age i.e. Pliocene, Mid-Miocene and Mid-Eocene. To evaluate the detailed composition of the rocks Neutron-Density crossplots are generated. Fig-4 shows different lithologies with fluids for the data from Pliocene formation to Mid-Eocene formation. The dominant lithology for Pliocene to Mid-Eocene top is sandstone and shale and that from Mid-Eocene to Log bottom is limestone and shale.

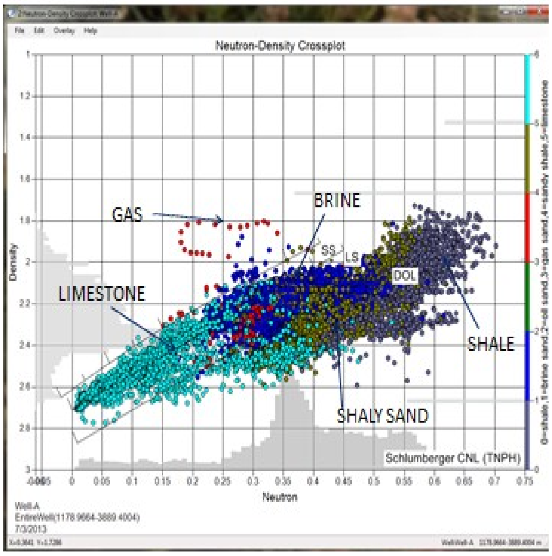


Fig-4: N-D Crossplot for lithology identification

Log processing has been done accordingly for estimation of petrophysical properties like the volume of minerals and shale, the porosity (both total and effective) and the hydrocarbon volume. These volumes will be the input for rockphysics modeling.

Rockphysics Modelling of Well A:

A cross plot has been generated in acoustic domain Vp versus PHIT (Total porosity) for the rock model that has been identified by petrophysical analysis. Since the well logs yield information on constituents and their volume fractions and relatively little about grain and pore microstructure, the bounds turn out to be extremely valuable rock physics tools. Fig-5 shows that the Sediments of Pliocene and mid miocene formations are unconsolidated and loosely packed and hence fall in the

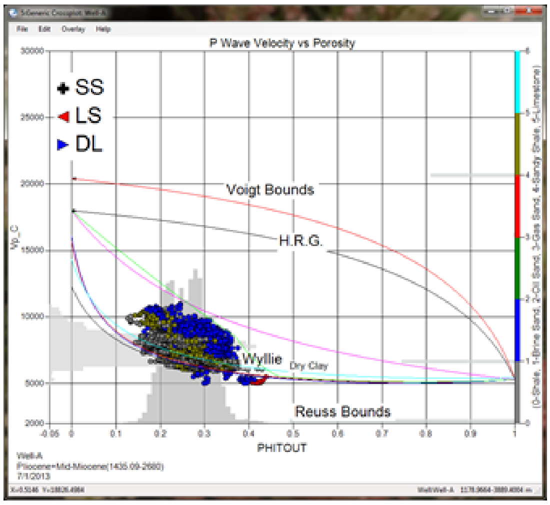


Fig-5: Vp-PHIT cross plot for Bounds

lower limit of Reuss bound for which the grain and clay aspect ratio are in lower range and the elastic constants K and μ will be an average of Reuss bound for Xu-White model.

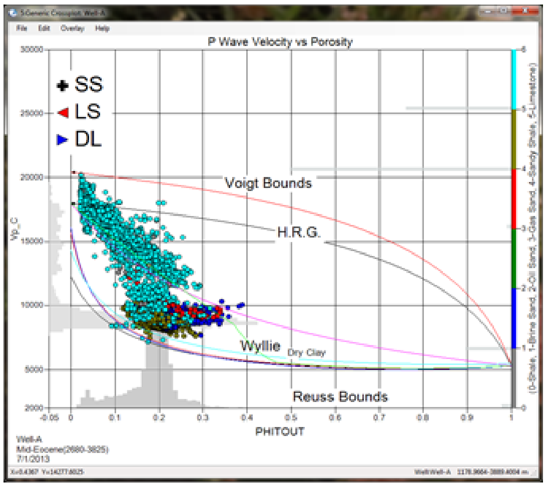


Fig-6: Vp-PHIT Crossplot for Bounds

Similarly, for Mid-Eocene age the sediments fall close to Ruess Bound but towards lower porosity range Fig-6. So accordingly the value of aspect ratio will be higher and values of K and μ will be different. These parameters and the volume obtained from petrophysics are incorporated in rockphysics workflow of Fugro Jason Powerelog RPM module to estimate the elastic logs (Vp, Vs & RHOB)

Petrophysics –Rockphysics Output

The well under study Well A had complete set of log suites (GR, CALI, LLD or RT, LLS, MSFL, RHOB, NPHI, DTCO and DTSM) Fig-7. Track- 1 to 4 shows the conditioned log data taken for petrophysical interpretation. Tracks- 5 and 6 show the output curves and the volumes generated respectively.Track-7 describes the lithology along with the fluids. Tracks- 8-10 are the elastic logs generated through rockphysics modelling which are free from borehole effects and invasion effect of the borehole fluid into the reservoir.

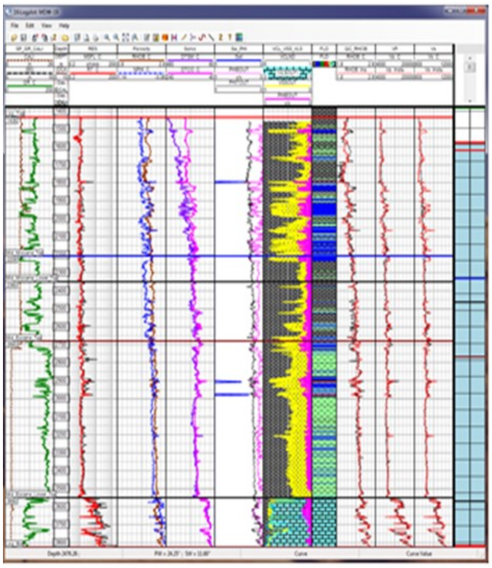
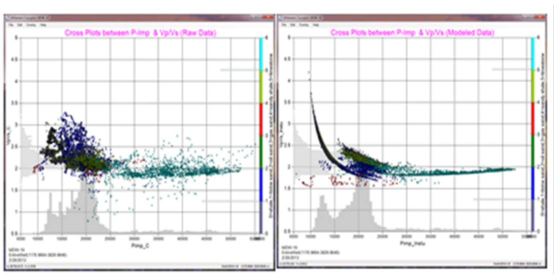


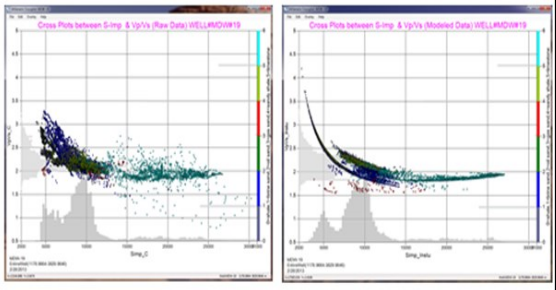
Fig-7: Petrophysics- Rockphysics Output

There is a fair match between the recorded and modelled log where the borehole is in gauged condition. However the modeled logs have been generated throughout the interval and are free from the invasion and borehole effect. This has improved the quality of logs as shown in crossplot Fig-8A and 8B.



Conditioned Data **Modelled Data**

Fig -8A:Crossplot of Pimp Versus Vp/Vs



Conditioned Data **Modelled Data**

Fig -8B: Crossplot of Simp Versus Vp/Vs

Once these elastic logs have been generated by RPM they are subjected to well to seismic tie as shown in Fig-9 which shows a fairly good match with seismic.

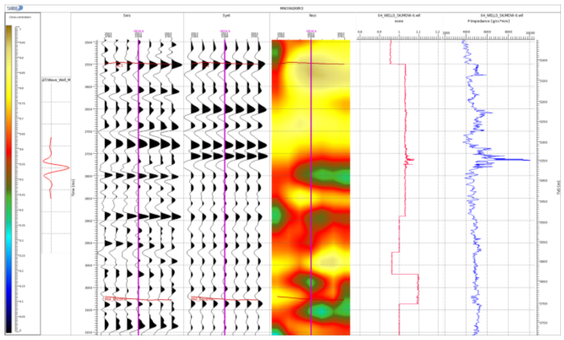


Fig-9: Well to Seismic tie shows good correlation

This data has been used for calibration of inversion results as shown in Fig-10.

Well-A.

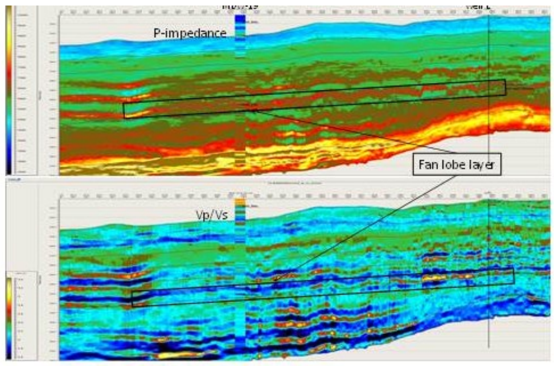


Fig-10:Inverted P-impedance & Vp/VsThrough Well-A

The gas charged Geobodies have been identified in acoustic impedance domain & calibrated with log data in 3D volume.

Conclusion

The reservoir with desired fluid and non- reservoir are differentiated with the help of elastic properties of formation. These elastic properties are obtained from elastic logs i.e, RHOB, Vp and Vs, which are responsible for generating seismic response.

The modelled logs (Vp, Vs, RHOB) are free from all perturbed effects (invasion, borehole, salinity, temperature) and are generated in situ conditions which provide the realistic picture of the seismic response in terms of lithology and fluid distribution.

The petrophysical interpretation has been transferred into elastic domain to understand the corresponding seismic response in the entire area. This approach has given an effective lead to the Seismic reservoir characterization guided by rockphysics.

Based on rockphysics analysis the identified gas charged geobodies have been delineated in 3D volume of the area as shown in Fig:10. This has given a lead for better seismic reservoir characterization.

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