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Building a realistic rockphysics model through in-depth petrophysical analysis for seismic reservoir characterisation and fluid identification: A case study

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Abstract:

Elastic rock properties are directly responsible for elastic wave propagation and seismic response in terms of P, S- wave velocities and Density. These responses are also associated with the reservoir properties like Ø, Sw, K, VCL and type of Fluid. To establish a link between elastic properties of the rock with the reservoir properties derived from the logs, a realistic rock physics model is needed. For better reservoir characterisation, in-depth petro-physical analysis is essential to estimate the formation volume components which will be the main input for rock physics model to generate elastic logs free from all borehole effects. Since the elastic property is the intrinsic property of any minerals in pure form but rock is the mixture of different minerals. Therefore, effective elastic property will play a crucial role in establishing the realistic rock-physics model which may yield real elastic logs Vp,Vs and Density.

Introduction:

Seismic and Petro-physical evaluation together can help us to identify and delineate the hydrocarbon bearing sands. Though the two data sources are complementary: seismic provides continuous lateral view of subsurface, whereas well logs yield fine vertical resolution of the geology at the borehole. Seismic profiles can resolve, with relatively high precision, the structural and stratigraphic changes from the arrival times and amplitudes of the reflection events. Well logs are measured in depth and provide high resolution vertical data, but no insight into the inter-well space. Seismic waves bring out subsurface rock and fluid information in the form of travel time, reflection amplitude,& phase variations and provide great lateral detail but is quite limited in its vertical resolution. When correlated, well logs and seismic can be used to create a fine-scale 3D model of the subsurface.
The elastic properties are the one, which can be obtained from both the well log and the seismic data. Thus for seismic reservoir characterisation we need to establish a relationship between petrophysical rock properties and elastic properties of the rock. This is made possible through Rock-Physics Modeling. This link allows the elastic properties of the rock determined through seismic inversion to be interpreted in terms of reservoir properties.
The present study, pertaining to Ultra deep area of KG Basin of India, an inclusion based model with Xu-White approximation has been applied to generate the elastic logs. These generated logs have good correlation with the recorded logs. The conceived rockphysics model has been applied to generate elastic logs in the wells where these logs are not recorded.
The elastic logs generated by Rock-Physics model have been used for well to seismic tie and low frequency model building. The petro-physical 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 reservoir characterisation guided by rockphysics.

Workflow:

The process begins with the log conditioning and detail petro-physical analysis for estimation of the mineral volumes and fluid contents. Once the volume of different components has been obtained, the next step is to find a rock physics model suitable for the Geological setup of study area. There are a number of rock-physics models available, which explain different types of sedimentary environmental process and their elastic properties. Once the model has been fixed it has to be applied in the wells where elastic logs have been recorded to find the sanctity of the model. The following sequential workflow was designed in order to achieve the objective of the project.

1. Understanding of the Area

This integrated study has been carried out for the pay sands encountered in four wells of Ultra deep area of Krishna Godavari Basin Fig.1. Four wells (A, B, C& D) have been taken for Petro physical evaluation followed by Rockphysics modeling for reservoir characterization and fluid distribution from Miocene top to Oligocene top. The selected wells have complete set of conventional log data (GR, SP, CAL, LLD, LLS, MSFL, RHOB, NPHI, DTCO and DTSM).

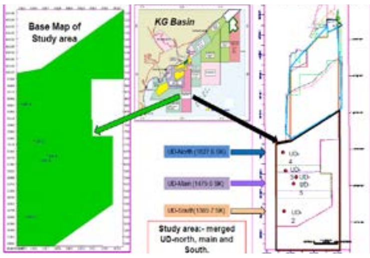

Fig-1: Location Map

2. Log data conditioning & Model Fixing

The conditioning process replaces unreliable and missing log measurements with synthesized values. Once well logs are properly conditioned and edited, they are first subjected to environmental corrections and then a petro-physical rock model is generated based upon the cross plot analysis and core studies.

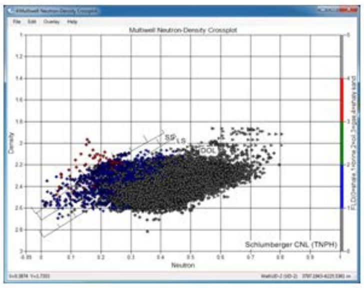

Fig-2-A Neutron-Density-Facies Crossplot

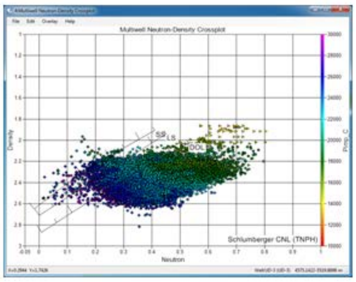

Fig-2-B Neutron-Density-P-Imp Crossplot

Fig-2-A&B Show different cross plots for lithological identification for petrophysical model.

This model will be used for detailed petrophysical analysis. The Petrophysical parameters a, m, n which are responsible for saturation estimation, generally obtained from laboratory are: a = 0.62, m = 2.15 and n= 2 and Rw = 0.1 ohmm at formation temperature (196degF) .These parameters are for Miocene Top to Oligocene Top. Water saturation Sw was calculated using Indonesian equation.

3. Petrophysical Analysis

Petrophysical analysis requires interpretation and processing of the log data to get the volumes of the constituent minerals, total and effective porosity and the saturation. The selected 4 wells were processed in STATMIN module of POWERLOG. Statmin is a statistical program that calculates lithology, mineralogy, and porosity and saturation. It delineates formation components in complex environments such as those containing sandstones of various mineralogy or carbonate environments in general.

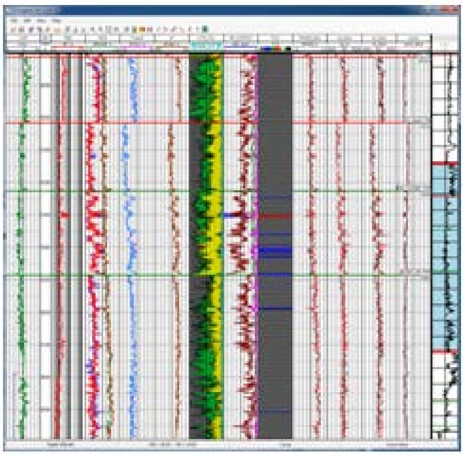

Fig. 3 Log Processed output

Statmin applies inverse statistical methods to a matrix containing log responses and uncertainty values for formation constituents. (These constituents are referred to as minerals but may include gas-filled or liquid-filled porosity.) The program uses the uncertainty value to calculate the standard deviation for each response and then uses the standard deviation to normalize the tool measurements and response equations. The program calculates the formation parameters by minimizing the difference between the normalized tool responses and reconstructed theoretical tool responses. To carryout inversion studies the log data has been processed from the Pliocene Top till the Oligocene Top for wavelet estimation in seismic data. The log signatures indicate it to be dominantly shaly with sand developments in between. Petrophysical properties like the volume of minerals and shale, the porosity (both total and effective) and the hydrocarbon volume has been estimated from this log processing Fig.3 . These volumes were used as main input for rock physics modeling.

4. Rock Physics Model:

There are many rock physics models that allow for the modeling of the elastic properties of rocks based on the volumes and the elastic properties of the component minerals and fluids. The elastic properties of the rock, other than density, are dependent on the micro-structure of the rock. Inclusion-based rock physics models account for the micro-structure mainly by assigning shapes to the pore space, and sometimes to the minerals.

Inclusion based rock physics model of Xu and White allows inclusion of material till the matrix get saturated, thus accounting for pore-pore interaction and permitting high porosities to be modeled. This model also accounts for the porosities associated with different minerals having different aspect ratio.

To predict the effective elastic moduli of a mixture of grains and pores we need to define

1. Volume fraction of various constituents.
2. The elastic moduli of each constituent.
3. Their geometric details, i.e., how these constituents are arranged to each other.

If we specify only the volume fractions and moduli of each constituent then we can predict the upper and lower bounds. For any given fraction of the constituents the effective modulus will fall between these bounds. The upper side values cause stiff pore shape while other soft pores shape. These pore shapes are responsible for propagation of wave front in elastic media at different velocities.

Fig-4 shows that the sediments fall near to Ruess bound which reveals the uncompact nature of sediments which causes the reduction in velocities. The rock physics model and parameters for this type of sediments is chosen accordingly.

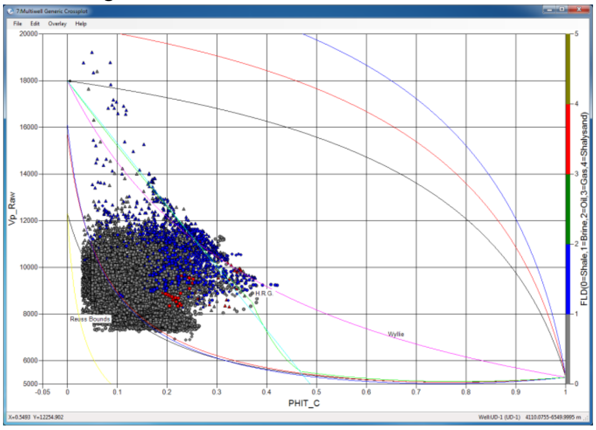

Fig. 4 Elastic bounds

5. The Voigt and Reuss bounds

The simplest, bounds are the Voigt and Reuss bounds. The Voigt upper bound on the effective elastic modulus, Mv, of a mixture of N material phases is ------------------------------------→ with *fi* the volume fraction of the *ith* constituent and *Mi* the elastic modulus of the *ith* constituent. There is no way that nature can put together a mixture of constituents (i.e., a rock) that is elastically stiffer than the simple arithmetic average of the constituent moduli given by the Voigt bound. The Reuss lower bound of the effective elastic modulus, MR, is ----------→ There is no way that nature can put together a mixture of constituents that is elastically softer than this harmonic average of moduli given by the Reuss bound.

$$M_V = \sum_{i=1}^{N} f_i M_i$$

$$\frac{1}{M_R} = \sum_{i=1}^{N} \frac{f_i}{M_i}$$

6. Rockphysics modelling:

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. Rock physics makes use of the mineral and fluid volumes from petro physics processed output. The total porosity and saturation are also obtained from log data processing. The other important input parameters required for rock physics modelling are grain and dry clay aspect ratio, clay and grain density, the compressional and shear velocity of clay, bulk and shear modulus of both grain and clay has to be taken from the published literatures.

7. Petrophysics and RockPhysics Modeling Workflow

Fig.5-A shows a complete workflow for generation of the elastic logs through rock physics modeling. The elastic logs thus generated through rock physics modelling (Vp_Mod, Vs_Mod and RHOB-Mod) are free from borehole and invasion effect and the quality of logs has been improved (Fig- 5-B). The correlation coefficient calculated between the recorded and modelled logs showed good correlation of more than 90%.

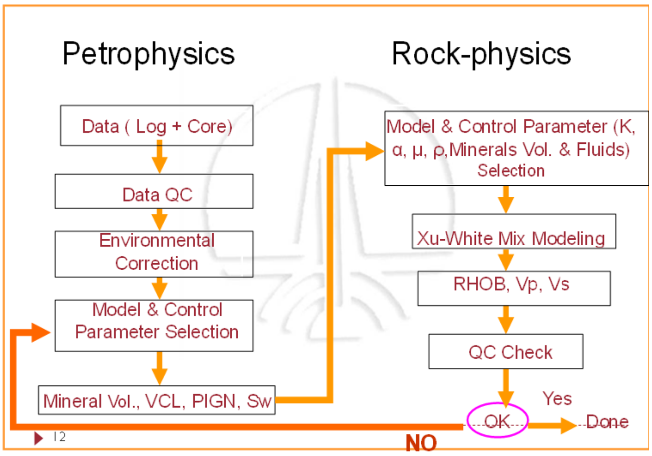

Fig. 5-A Petrophysics – Rockphysics

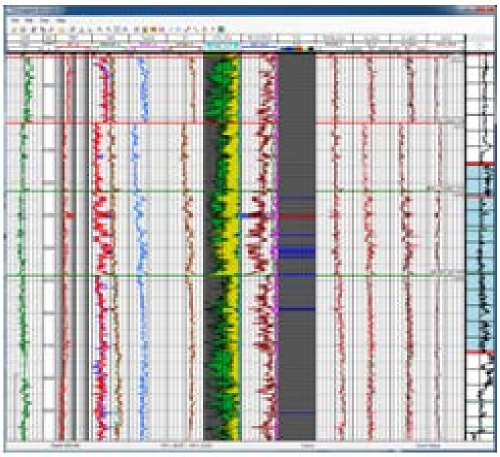

Fig. 5-B PP_RP Output

8. Analysis of Rockphysics output:

A cross plot has been taken between P Impedence and Vp/Vs both for raw and rockphysics modelled logs Fig. 6-A & 6-B respectively. These plots clearly show that in the modelled data, there is a clear cut demarcation of gas, water and shale in different range of Vp/Vs domain.

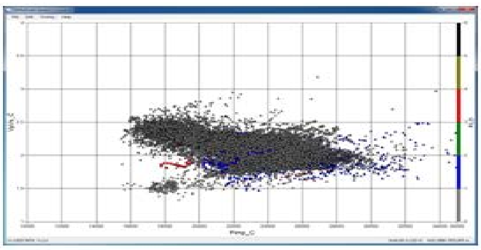

Fig. 6-A Cross Plot P_Imp & Vp/Vs (Raw Data)

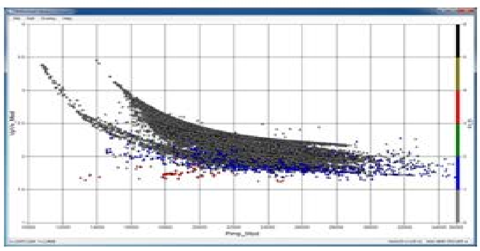

Fig. 6-B Cross Plot P_Imp & Vp/Vs (Mod. Data)

9. Application in Seismic Inversion

Rock physics modeled (RPM) logs were used for well to seismic tie & Wavelet extraction Fig.7-A and interpretation of the lithology with fluids. The wavelets of all the four wells under study were similar in characteristics and stable for all angle stacks. Synthetic to seismic correlation was also good for all the angle stacks. Fig. 7B shows seismic calibration with logs and Fig. 7C shows inversion results of P-Impedance, S- impedance and Vp/Vs.

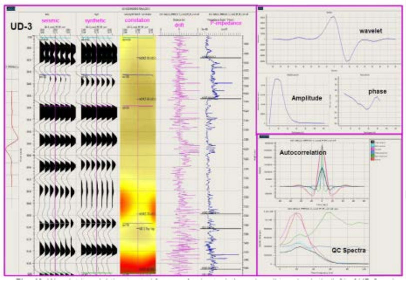

Fig. 7-A: Well to seismic tie and Wavelet extraction

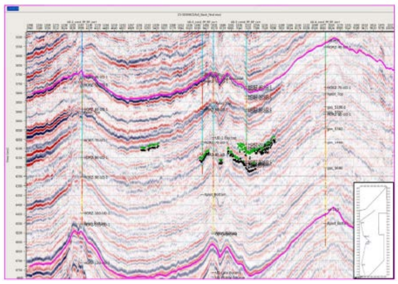

Fig. 7-B: Seismic calibration with logs

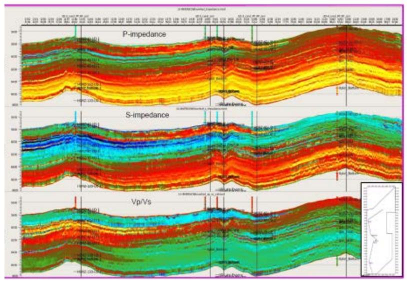

Fig. 7-C: inverted P-impedance, S-impedance and Vp/Vs

Conclusion:

The elastic logs generated by Rock-Physics model have been used for well to seismic tie and low frequency model building. The petrophysical interpretation has thus 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 characterisation guided by rockphysics model.

Petrophysical and Rockphysics Study reveals:

- The rock physics modelled logs are free from invasion and borehole effects
- Cross plots of Vp versus Vs indicates improvement in the modeled logs
- Cross plots of Pimp versus Vp/Vs shows clear demarcation of gas.
- The modeled logs has been used for seismic reservoir characterisation

Inversion Study reveals:

- Gas sand polygon selected from cross plot of extracted P-impedance and Vp/Vs of four wells and is used to delineate most probable gas sand.
- Inversion results at unknown well shows good match with well log P- impedance and Vp/Vs.

The distribution of the reservoir sand at and away from the well location could be delineated from this simultaneous inversion

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