

Identification of gas charged thin and discontinuous sand bodies through pre-stack geostatistical inversion and rockphysics modelling– A case study

B.S.Bisht, Beena Jhaldiyal, S.K. Singh, GEOPIC, (ONGC Dehradun), India

Presenting Author: B.S. Bisht*

Email: bisht_bs@ongc.co.in, birsingh.bisht@gmail.com

Keywords

Petrophysics, rock-physics, petro-elastic modeling, seismic reservoir characterization, geo-statistical inversion

Summary

Integration of sub surface vertical geological variation identified through well log data with the lateral variation picked up by the seismic signals received at the surface helps in identifying and delineating a reservoir body which is interesting from hydrocarbon point of view. The analysis of log data helps in understanding and assessing the rock petrophysical properties like lithology, fluid content and porosity. Seismic inversion process converts seismic reflectivity to elastic properties of the sub surface.

Seismic trace is the result of convolving the reflectivity function of the earth on the wavelet where the reflectivity is the ratio of the amplitude of reflected wave to the incident wave which is an elastic property. If somehow this elastic property is related with reservoir property of interest then the interpretation of seismic response become easier and meaningful.

The elastic properties of the rock i.e. density, V_p & V_s are responsible for generating seismic response which is also influenced by the rock petrophysical properties. Therefore it becomes essential to have a link between these two properties. Rockphysics is a science which established a link between rock petrophysical & elastic properties. This link will help to interpret the seismic response in terms of petrophysical/reservoir property of the rock.

Introduction

Study area, C-39, covers northern part of Tapti-Daman block (Fig.-1). This offshore block lies in the North North Eastern part of Mumbai offshore basin located in the Western Continental Margin of Indian subcontinent and is considered to be the southern extension of Gulf of Cambay. Oligocene sands have

been proved to be hydrocarbon bearing in this area. Pay sand thickness varies from 2-8 m in Upper Mahua formation which are mainly gas bearing reservoirs.

The area of study is around 238 Sq. Km. Bin size of available seismic data is 25m X 25m. Pay sand thickness varies from 2-8 m in the area. This order of pay thicknesses is of sub-seismic resolution as dominant frequency available in seismic data is only 22 Hz with a bandwidth of 6-40 Hz. Pre-stack deterministic inversion is not able to fulfill the objective of the study. Therefore Pre-stack geostatistical inversion was carried out to investigate the possibility of mapping thin pay sands within known limitations of input data. This study, could bring out most probable pay sands distribution which was supported by other G&G studies and reasonable test wells validation.

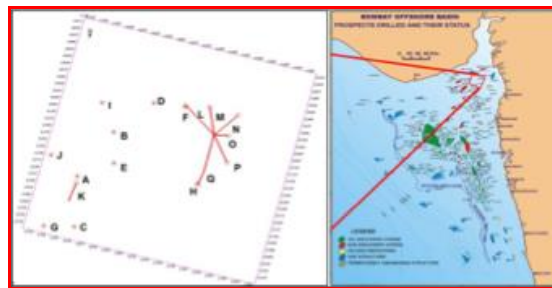


Fig:-1 Area of Study

This paper highlights role of rock physics modeling in establishing a relationship between petro-physical evaluated reservoir properties and elastic properties of the rock to be further used in geostatistical inversion for identification of thin sands. The relationship helps in generating elastic logs in wells where it is not available and thus providing uniform

Pre-stack geostatistical inversion and rockphysics modelling

elastic log availability over the entire study area. Further the cross plots generated between P-impedance versus V_p/V_s with litho-fluid curve in Z-axis help in discriminating various lithologies with different types of fluids in each well covering the study area. Separation between pay and non-pay sand was visible in V_p/V_s domain and not in the impedance domain. This discrimination will be used for identification of the geobodies in the inversion process.

Workflow

The following sequential workflow has been adopted for this process:

Log data conditioning

The recorded log data has very high resolution and can identify very fine different geological unit as compared to any other recorded data. The log data during drilling process gets affected by borehole rugosity, invasion, mud cake formation, salinity, temperature & pressure etc. Sometimes the logs could be entirely missing or not usable due to bad hole conditions. The analysis made on such unreliable data may lead to wrong identification & estimation of litho-fluid type. To avoid this data conditioning is done. Synthetic logs need to be generated by multiple linear regression techniques based on the other logs to fill the missing data gap. Once the data gap is filled necessary environmental corrections are applied along with the appropriate filter for spike and noise removal. This conditioned data is now suitable for further analysis.

Petrophysical Analysis

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. For determination of rock petrophysical properties an adequate logging suit is necessary which can measure the desired property accurately. Once the Petrophysical model has been fixed, it will be applied for estimation of the reservoir parameters i.e. Effective Porosity (Φ), Water saturation (S_w) and Volume of Clay (VCL) using multi-mineral inverse optimization technique. This technique takes into account the effect of conductive or nonconductive, heavy minerals, radioactive minerals and different

clay contents reported in core studies. A cross plot of Thorium-Potassium and Neutron-Density generated for clay mineral identification. This plot indicate presence of Kaolinite as the dominant clay mineral in the study area. Presence of Chlorite and illite were also observed in less propositional (Fig-2).

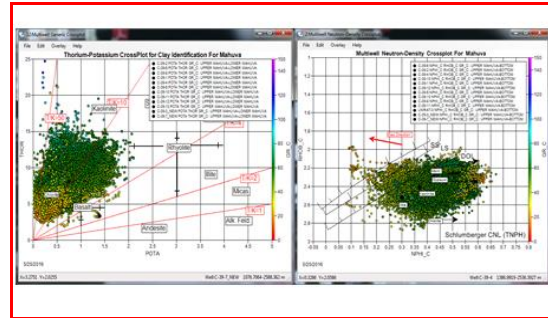


Fig:-2 Thorium-Potassium and Neutron-Density

Based on cross-plots analysis, Well completion, core and Petrophysical reports sand-shale interpretation model has been used in STATMIN module of Powerlog where shale has been taken as a mixture of Kaolinite and other clay mineral varying from well to well. The petrophysical parameters for processing were taken as $a = 0.81$, $m = 2.0$ and $n = 2.0$. Fig- 3 shows the petrophysical output of a well-A

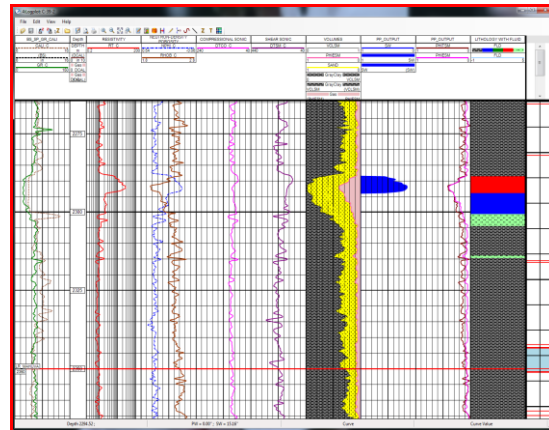


Fig:-3 Petrophysical analysis

Rockphysics:

Rock-physics transform petrophysical results into elastic properties that can be used for seismic inversion. This complementary nature of Petrophysics and Rock physics requires a tight

Pre-stack geostatistical inversion and rockphysics modelling

integration for seismic reservoir characterization. Well log data plays a crucial role in this process of integration. In general, most of the times petrophysical evaluation, petro-elastic modeling and synthetic to seismic tie are done separately prior to integration. This introduces uncertainty and inconsistency across the geo-scientific data. Ideally, Petrophysics and Rock physics modeling should be an integrated process that can produce a greater consistency between all the data and lead to reduce uncertainty (Fig-4).

The Rock Physics uses a phase drive mixing method or combination of methods to combine elastic properties of the minerals and fluids that predict the measured elastic logs i.e. density, P-velocity and S-velocity. The derivation of a modeling is complex task with iteration loop involving rock physics, log conditioning and petrophysical analysis. The minerals and pores space are mixed and then the fluids are filled, finally the other fluids are also introduced into the porous mineral via Xu-White modeling method.

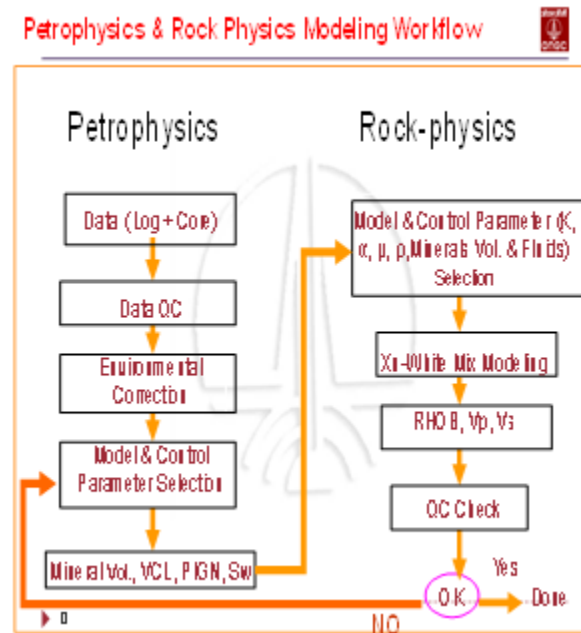


Fig:-4 Integrated workflow

The Petrophysical model output i.e. Volume of minerals, Volume of clay, total porosity fluid

saturation has been taken into the rockphysics model to estimate the elastic logs i.e. Vp, Vs and Density through velocity Mix function using Xu-White approximation (Fig-5).

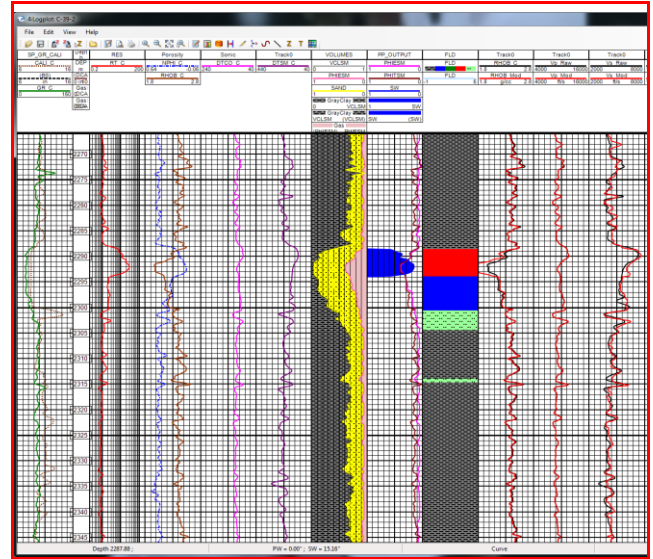


Fig:-5 Shows the output of Petrophysics and Rockphysics. The elastic logs generated through rockphysics modelling match well with the recorded logs

The elastic logs generated through rockphysics modelling (Vp_Mod, Vs_Mod and RHOB-Mod) are free from borehole and invasion effect and thus the quality of log improves. Also in wells where shear sonic was not available, modelled shear velocity was generated through rockphysics modelling.

Good correlation exists between the measured and modeled elastic logs (P-velocity & Shear velocity) for all wells under study area (Fig-6).

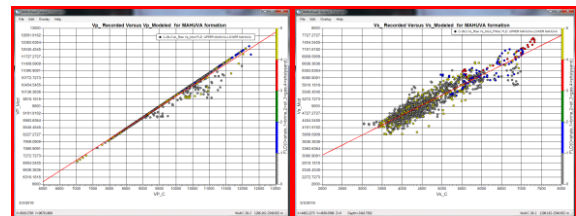


Fig:-6 Correlation of measured & modelled logs

The modelled elastic logs are further used for Pre-stack geo-statistical inversion study and finally to

Pre-stack geostatistical inversion and rockphysics modelling

reservoir properties generated by such approaches decreases rapidly away from well control since the seismic data is only used as a stratigraphic guide or trend.

The second approach consists of using deterministic seismic inversion results to populate a model with reservoir properties. Limitations of the second approach are: low vertical resolution since the properties are accurate only within seismic bandwidth, the inverted properties generally do not coincide precisely with measured well logs, and only one solution exists. On the other hand, the advantage of such models is that they provide independent estimation of reservoir properties from seismic data between the wells and have a much higher lateral resolution.

Geostatistical inversion is a methodological approach having advantages of the two approaches of geological modelling mentioned above. It generates stochastic realizations of lithology and elastic properties of a reservoir, which not only reproduce prior lithology probability trends, spatial variograms, and joint probabilistic distributions of elastic properties but also reproduce the measured well logs and closely match the 3D seismic data within the desired noise levels.

One of the differences between deterministic and geostatistical inversion is the creation of an a priori model where deterministic inversion does not use any prior model but instead uses low-frequency trends of elastic properties together with other constraints to define the solution area. In the geostatistical inversion approach, a geostatistical prior model is used to capture various kinds of probabilistic geological knowledge about the reservoir structure, such as spatial property consistency in the form of 3D variograms and the range and multivariate distributions of elastic properties for each lithology type and geologic zone as probability density function.

A Geostatistical inversion was conducted to improve the inversion details and assess model uncertainty. The uncertainty becomes even more important where pay thickness is beyond seismic resolution. The main objective of these kind of studies are to delineate the most probable distribution of reservoir facies.

Geostatistical inversion involves geostatistical modeling and deterministic inversion simultaneously, in a statistically rigorous way. It assumes that subsurface is a realization from a given geostatistical model of rock and reservoir properties (e.g. elastic parameters like P-impedance, S-impedance, lithology and porosity). It finds rock and reservoir properties consistent with the assumptions and the seismic data. It also admits that there are many other reasonably consistent possibilities. The benefits of geostatistical inversion are:

1. Joint inversion of elastic properties (P & S impedances) and lithology.
2. Estimates uncertainty for risk assessment.

Geostatistical inversion results

Most probable facies volume and pay sand frequency volumes were analysed and compared with well observations at well locations (Fig-10 & 11).

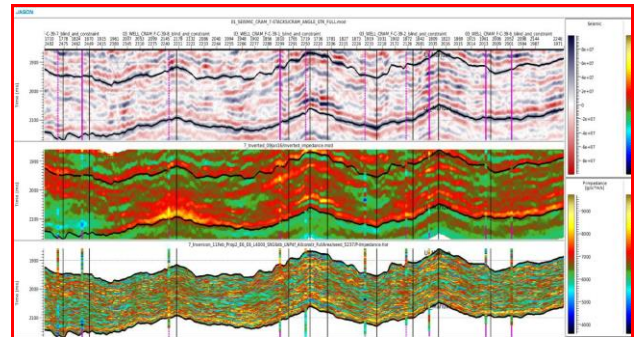


Fig:-10 Comparison of P-impedance from deterministic and a representative realization of GI. It shows more details in GI

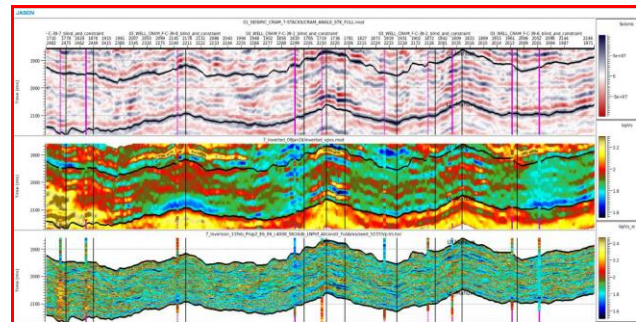


Fig:-11 Comparison of Vp/Vs from deterministic and a representative realization of GI. It shows more details in GI

Pre-stack geostatistical inversion and rockphysics modelling

Geobodies were extracted with pay probability of >50% in the volume. Variation in colour shows the vertical disposition of the bodies in time (Fig-12).

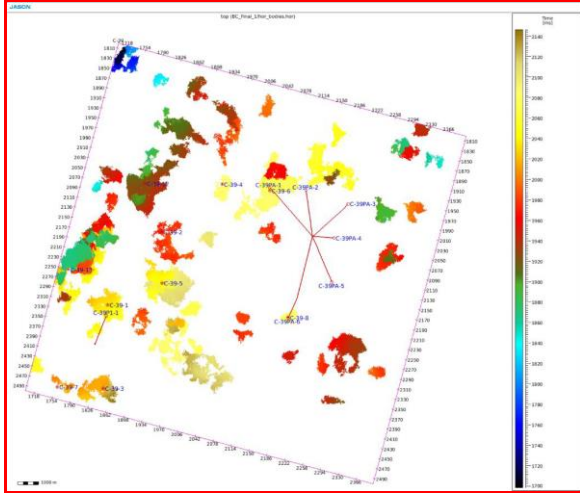


Fig:-12 Extraction of geobodies

Discussion of results:

1. Rockphysics Modeling

1. Rockphysics modelling has improved the quality of recorded elastic logs, i.e. V_p , V_s and $RHOB$ in the wells where shear sonic log was recorded.
2. Rockphysics modelling has generated elastic logs i.e. V_p , V_s and $RHOB$ in the wells where shear sonic log was not recorded.
3. Modelled elastic logs are able to discriminate reservoir with fluid from non-reservoir.
4. These modelled elastic logs will be used for Pre-stack seismic inversion study and finally to identify hydrocarbon bearing sand bodies in 3D volume.

2. Geo-statistical Inversion Study

Pre-stack geostatistical inversion broadly explains the finding in all the wells including deviated wells. Distribution of thin pay sands at different levels could be deciphered keeping in view the associated uncertainties.

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. The distribution of the reservoir sand at and away from the well location could be delineated from this simultaneous inversion. This approach has given an effective lead to the seismic reservoir characterization guided by rockphysics model.

Acknowledgement:

The authors are indebted to Shri A. Bhardwaj, ED-HOI-GEOPIC, Dehradun, India for providing the technical input and guidance for writing this paper. Thanks are due to Shri Dr. Hari Lal, Head-INTEG, GEOPIC, Dehradun, India for providing all kind of support for this work. The authors are grateful to Mr. Hemant Dixit, Dr. Ranjeet Shaw & Akash Mathur of CGG, Geo-software Mumbai for their software & technical support during this study.

Knowledge sharing of concerned geoscientist of this domain for providing necessary input during the project work and writing this paper is also acknowledged. We thank ONGC management for allowing us to submit this paper in 12th Biennial International Conference & Exposition of SPG-2017

The views expressed in this paper are solely of the authors and do not necessarily reflect the view of ONGC

Reference:

1. Serra Oberto, Well Logging. Vol. 3 Well Logging and Reservoir Evaluation
2. Mark Sams1* and Thomas Focht 2, An effective inclusion-based rock physics model for a sand–shale sequence
3. Mavko, G., Mukerji, T. and Dvorkin, J., The rock physics handbook: tools for seismic analysis in porous media. Cambridge University Press.
4. Joel Walls, Jack Dvorkin, Matt Carr, Well Logs and rock physics in seismic reservoir characterization
5. Xu, S., and White, R.E., A new velocity model for clay-sand mixtures: Geophysical Prospecting 43, 91-118.