Role of Rock Physics in Improving Seismic Reservoir Characterization of discrete Sands of a Complex Reservoir from Western Off-shore Basin, India.

Suresh Konka, Sudhesh Babu, S S Pabla, S S Dash, A Sai Kumar and A C Naithani, Oil and Natural Gas Corporation, India*

dnbdsuresh@gmail.com

Key Words

Geo-statistical, Inversion, Impedance, Rock-physics, Petro-physics, Facies.

Summary

Rock physics represents the link between reservoir parameters to elastic parameters and it can help in understanding the behavior of the reservoir and non-reservoir zones. Reflection seismic provide image of the subsurface in elastic properties domain, and a rock physics model is needed to convert them into reservoir properties which are more familiar for the geoscientist and engineers. In present study Panna formation is dominated with shale sequences with intercalations of sand and coal facies is traditionally difficult to identify on conventional seismic data. The average bed thickness is 6 meters which is beyond the resolution of typical seismic. To identify and map discrete and thin sands rock physics modeling carried out for panna clastics using Xu-White (1995) model designed to describe the velocity – porosity relationships of clastic rocks was used to model elastic properties density, P-wave velocity (Vp) and S-Wave velocity (Vs) based on the petro-physical results. Rock-physics analysis indicated that sands and shales have P-wave impedances that overlap to the extent that it is difficult to discriminate between them. However, they can be separated in a cross-plot of Vp/Vs versus P-wave impedance. Using these modeled outputs post-stack geo-statistical seismic inversion was carried out to delineate discrete sand bodies. Rock-physics modeling combined with higher resolution reservoir characterization of geo-statistics inversion gave the connectivity of sand bodies within the target zone. The final reservoir spatial distribution shows the sandstone's discontinuity and horizontal thickness trend. The business impact is that, this analysis combing with other G&G studies helps to interpret the locations of thicker and more porous sand bodies. Our study shows that the integrated petro-physical analysis, rock physics modeling and seismic analysis results in improved reservoir characterization of discrete and thin sands of complex panna formation.

Introduction

Seismic Reservoir Characterization, also known as reservoir geophysics, has evolved over the past several years into a multi-disciplinary, business-critical function in most ED&P organizations (Walls et al., 2004). Reflection seismic helps with creating 2D or 3D image of the reservoir by providing the subsurface seismic properties. These properties can be used to construct structural frame of the subsurface using different attributes. Further information can be extracted applying different seismic characterization methods such as Amplitude Versus Offset (AVO), inversion etc. However, all of these methods provide an image within elastic properties domain, and a rock physics model, which models elastic properties density, P-wave and S-wave velocity is needed to convert them into reservoir properties which are more familiar for the geoscientist and engineers (Saberi, 2013).

Rock physics models can be derived many different ways. Empirical models are very common. If well logs or laboratory measurements on core samples are available, then these data can be a good source to generate a local relationship between a few required properties, such as P-wave or S-wave velocity and porosity and Vclay. However, these relationships are typically linear and may or may not be extensible to locations away from the regional calibration area (Payne, 2008). In this study we have applied an analytical Xu-White rock physics modeling that incorporates all known physical and geological effects.

In this paper, we show a case study from a fluvial depositional environment. The business challenge is to identify and map the discrete and thin sand bodies so that several wells can be efficiently drilled. In this study, rock-physics analysis indicated that sands and shales have P-wave impedances that overlap to the extent that it is difficult to discriminate between them. However, they can be separated in a cross-plot of Vp/Vs versus P-wave impedance. In this paper, we also discuss a case study that demonstrates the importance of a rock physics model combined with geo-statistical inversion for to delineate discrete and thin sand bodies in a complex reservoir.

Area of study

The study area falls in the western offshore basin of India with a bathymetry is around 40m and is located 20-25 km east of Mumbai high field Figure 1.

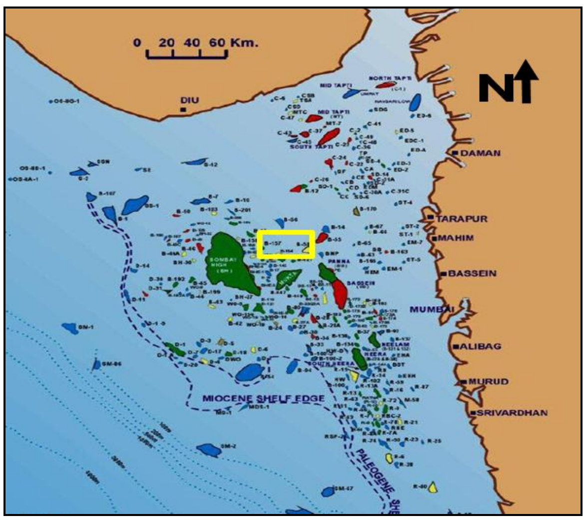

Figure 1: Location map of study area

The major reservoirs are limestone in Bassein and clastics in Panna formation. Oil and gas reservoirs are established within Panna formation at four different layers. Mumbai offshore basin is proved to have been endowed with intricate source, reservoir and seal facies assemblage in the panna formation of Paleocene – Early Eocene age. The syn-rift sediments comprising lacustrine source rocks are highly potent and capable of generation of hydrocarbon. The recent studies have shown multiple mature source intervals within Panna formation with organic matter and excellent generation potential. The average TOC (Total organic carbon) of Panna formation ranges from 0.5-3.0% and VRo (Vitrinite reflectance) as 0.4-3.6% (fair to good maturity). Strati-structural entrapment is envisaged for the prospects in the Panna formation. The Panna clastics, which have reservoir facies are derived from Trap /Granite /Metamorphic highs and deposited in continental to marginal marine environment. The transgressive marine shale within Panna formations acts as seal. The black carbonaceous shale which is deposited in marshy near shore environment also acts as top/lateral/juxtaposition seal locally over individual sand reservoir.

Total five wells Well - A, B, C, D & E are considered for rock-physics modeling. Figure 2 shows base map of study area with well locations.

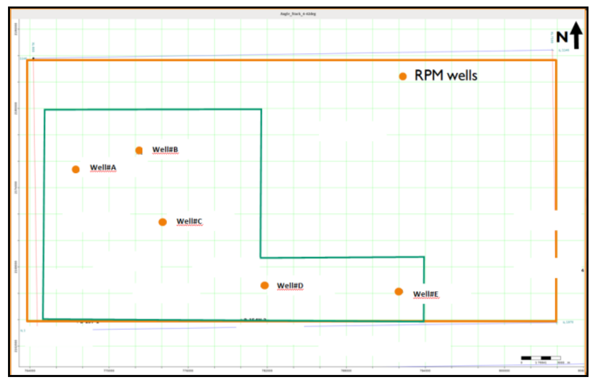

Figure 2: Base map with well locations

Petro-physics to Rock-physics

Panna formation is having a very complex lithology comprising of heavy minerals (trap wash), sandstone, siltstone, shale and coal bands. Petro-physical analysis for five wells is carried by integrating with core study, nuclear magnetic resonance data, and elemental capture spectroscopy data to accurately evaluate mineralogical volumes (Figure 3). Petro-physical interpretation provides volume of minerals, the porosity (both total and effective) and the hydrocarbon volume and these are the essential inputs for rock-physics modeling. The elastic properties (Vp, Vs, RHOB) depend upon a number of reservoir properties like facies, fluids, porosity, saturation, pressure, stress, 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 will lead

Role of Rock physics Modeling in Improving Seismic Reservoir Characterization of discrete Sands of a Complex Reservoir from Western Off-shore Basin, India.

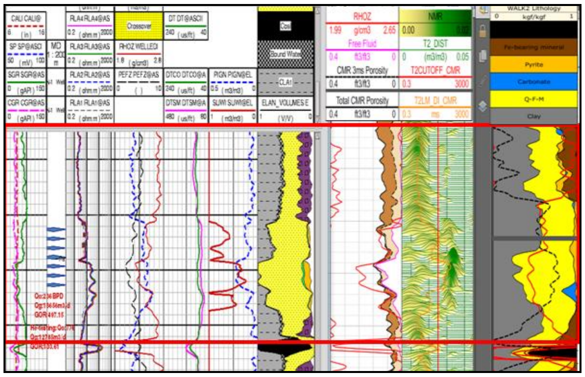

Figure 3: Integrated petro-physical evaluation of Well#A .

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.

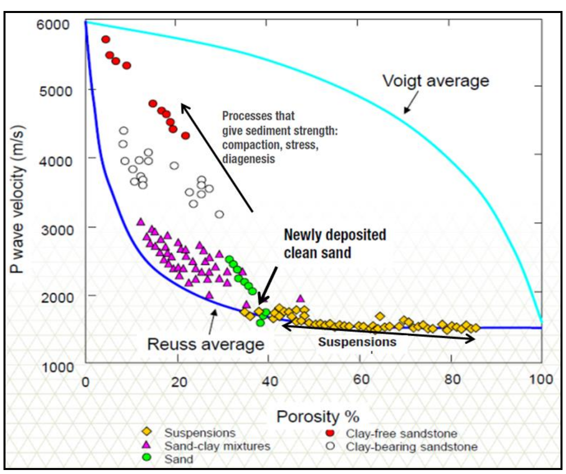

Figure 3: P-wave velocity versus porosity for a water saturated sediments. (Marvko, G, 2009)

Figure 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) 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.(Avseth et.al.,2009).

A cross plot has been generated for Well#A in acoustic domain Vp versus Total porosity (Figure 4) . 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.

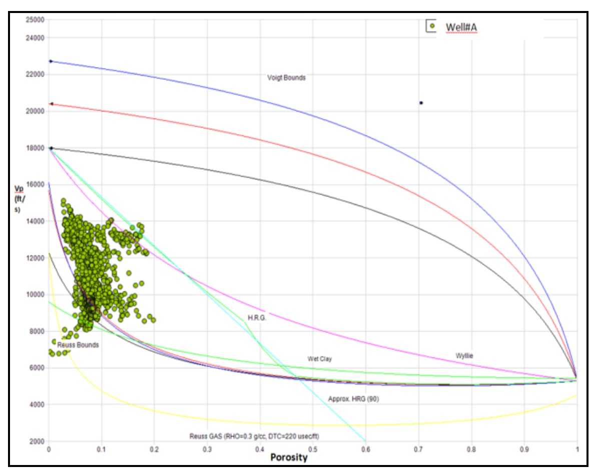

Figure 4: Vp versus Porosity plot of Well#A.

Role of Rock physics Modeling in Improving Seismic Reservoir Characterization of discrete Sands of a Complex Reservoir from Western Off-shore Basin, India.

Figure-4 shows that the Sediments of Panna formations fall away from Ruess Bound but towards lower porosity range. 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 petro-physics are incorporated in rock-physics workflow to estimate the elastic logs.

Xu and White (1995) proposed a clay-sand mixture model based on the Kuster and Toksoz (1974), Gassmann (1951) and differential effective medium (DEM) theories, which related P-wave velocity in sand-shale systems to porosity and clay content. The model has two key features. The first is that it characterizes the compliances of the sand and clay mineral fractions of the rock by assigning to them separate pore spaces having different effective pore aspect ratios (ratios of short semi-axis to long semi-axis). The second key feature is the use of Kuster-Toksoz (1974) and DEM theories to compute the elastic moduli of the dry frame. Given the dry frame moduli, application of Gassmann's (1951) equations then gives the low-frequency velocity in the fluid saturated rock.

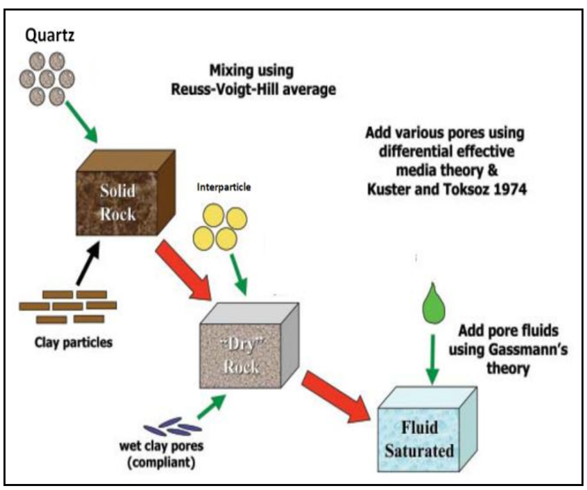

Figure 5: Schematic diagram of Xu – White RPM.

The cross-plot of modeled P-impedance versus Vp/Vs log colored with facies discriminate between reservoir and non-reservoir. Facies codes are 1. Shale, 2. Gas, 3. Oil, 4. Water, 5. Limestone, 6.Shaly Sandstone, 7.Coal

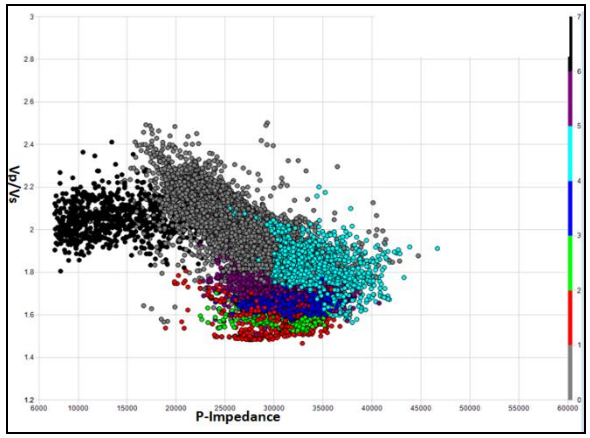

Figure 6: P-impedance vs Vp/Vs ratio plot of 5 wells.

Rock physics to Seismic

Well to seismic tie of 5 RPM wells was done using angle stacks to carry out Pre-stack geo-statistical inversion (Figure 7). Multi-well wavelet has been extracted. Constrained pre-stack geo-statistical inversion was run for several realizations. Figure 8 display the most probable sand distribution along the well. The probability section clearly indicates that reservoir facies within panna formation are not continuous and discrete in nature and are very thin. Figure 9 shows the sand distribution map. The integrated petro-physical analysis, rock physics modeling and seismic inversion studies has improved the reservoir characterization by mapping discrete and thin sandstone reservoirs. The business impact is that, this analysis combing with other G&G studies helps to interpret the locations of thicker and more porous sand bodies.

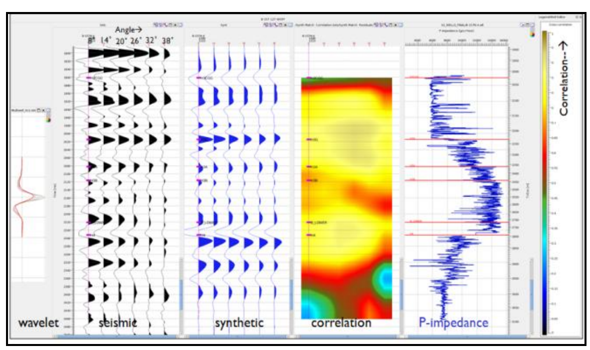

Figure 7: Well to seismic tie of Well#A.

Role of Rock physics Modeling in Improving Seismic Reservoir Characterization of discrete Sands of a Complex Reservoir from Western Off-shore Basin, India.

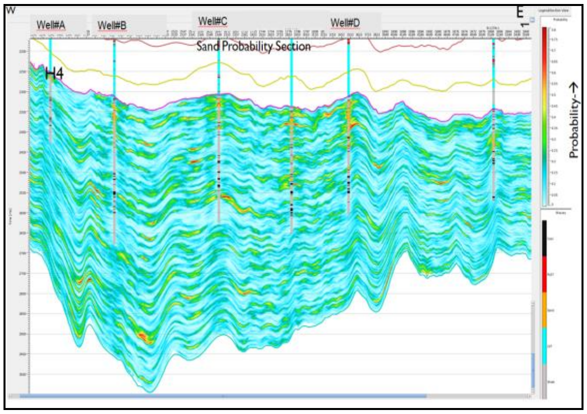

Figure 8: Probable distribution of sand facies.

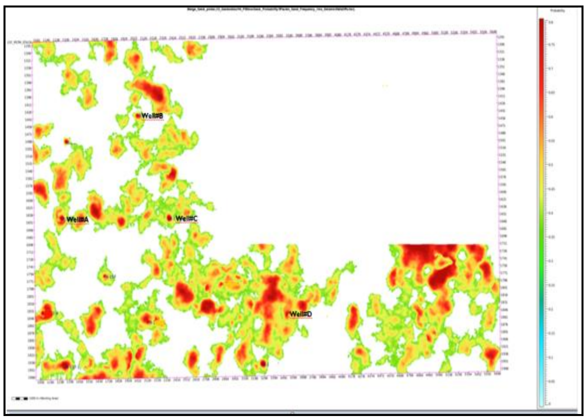

Figure 9: Sand distribution map within panna

Conclusions

In this study, we have applied Xu-White rock-physics method to model elastic properties Vp, Vs and density logs. The reservoir and non- reservoir are differentiated with the help of elastic properties of formation. 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. Constrained pre-stack geo-statistical inversion was run for several realizations. sand probability section of panna formation shows the most probable sand distribution along the well. The probability section clearly indicates that reservoir facies within panna formation are not continuous and discrete in nature and are very thin. The integrated petro-physical analysis, rock physics modeling and seismic inversion studies has improved the reservoir characterization of by mapping discrete and thin sandstone reservoirs of panna formations. The business impact is that, this analysis combing with other G&G studies helps to interpret the locations of thicker and more porous sand bodies.

Acknowledgement

The authors are indebted to Shri Pradipta Mishra., ED-HOI-GEOPIC, Dehradun, India for providing all kind of support for this work. We thank ONGC management for allowing us to submit this paper in SPG - 2019. The views expressed in this paper are solely of the authors and do not necessarily reflect the view of ONGC.

References

Zhang, W., Sun, Z., Ming, Z., Sun, Z., and Wang H., 2012, Integrated seismic inversion to predict thin fan delta sandstone and fluid: A feasibility study case in Junggar Basin China: SEG Annual Meeting, Las Vegas.

Walls, J., and Dvorkin, J., 2004, Well Logs and Rock Physics in Seismic Reservoir Characterization: Offshore Technology conference.

Xu, S. and Payne, M. A., 2009, Modeling elastic properties in carbonate rocks: The Leading Edge.

Saberi, M. R., 2013, Rock Physics Integration: From Petrophysics to Simulation: 10th Biennial International conference & exposition.

Payne, M. A., 2008, Rockphysics as the basis for imaging Geophysical observations: SEG Annual Meeting, Las Vegas.

Mavko, G., Mukerji ,T., and Dvorkin, J., 2009, The rock physics handbook: tools for seismic analysis in porous media: Cambridge University Press.

Liu, E., Payne, M. A., Xu, S., Baechle, G. and Harris, C.E., 2009, Carbonate Rock Physics Issues: International Petroleum Technology conference, Doha, Qatar.