PaperID **AU484**

Author **Konka Suresh , Oil and Natural Gas Corporation Ltd , India**

Co-Authors **Puja Prakash, Jagdamba Prasad**

Role of rock physics modeling in improving seismic reservoir characterization of carbonate reservoirs from an Off-shore carbonate field.

Abstract

Rock physics modeling 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. Carbonates are known for their complexity in pore geometry and network hence an accurate, robust and practical rock physics model is essential for reservoir characterization. In this study, carbonate rock physics modeling carried out for carbonate reservoir of an offshore carbonate field using rock physics model of Xu-Payne (2009) which was formulated by modifying the Xu-White (1995) model originally designed to describe the velocity – porosity relationships of clastic rocks was used in the study to model density, P-wave velocity (Vp) and S-Wave velocity (Vs) . Using these modeled outputs post-stack seismic inversion was carried out. The P-impedance and Vp/Vs template from modeled logs as well as logs extracted from seismic inversion at all well locations, can able to differentiate between Oil limestone, water bearing limestone and shale. A most probable hydrocarbon zone was extracted from inverted seismic sections and this will be useful in identification of geo-bodies. This analysis combing with other G&G studies helps to firm up the indentified prospects. Our study shows that the integrated petro-physical analysis, rock physics modeling and seismic analysis results in improved reservoir characterization of carbonate reservoir.

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 density, Vp and Vs logs is needed to convert them into reservoir properties which are more familiar for the geoscientist and engineers (Saberi, 2013).

Development of a carbonate rock physics model is extremely difficult because pore systems are more complex in carbonate rocks than they are in clastics. While clastic rocks have mainly intergranular pores, carbonate rocks can have a variety of pore types, such as moldic, vuggy, interparticle, and intraparticle. Diagenesis often plays a significant role in the development of such a pore system. The complex pore system makes the porosity velocity relationship highly scattered. Recent experimental results indicate that pore type can cause as much as a 40%change in P-wave velocity for a given porosity. Pore shape appears to be the dominant factor in carbonate rock physics. In general, moldic, intraframe, and vuggy pores tend to be rounded and make the rock stronger (faster) than when the pores are interparticle. On the other hand, micropores, e.g., microcracks, tend to be flat and make the rock weaker. To effectively characterize carbonate reservoir rocks, it is critical to develop a rock physics model capable of handling different pore types (Xu et al., 2009).

In this paper we will discuss about the role of carbonate rock physics modeling in seismic reservoir characterization. The current study carried with an Objective to perform seismic reservoir characterization to decipher the most probable distribution through seismic inversion studies with the help of petro-physical analysis, rock physics modeling. A total of 5 wells namely Well#A, B,C & D are considered for the study, out of which only one well, Well#A is having shear logs recorded to build and calibrate rock physics model. Figure 1 shows base map of study area with location of wells.

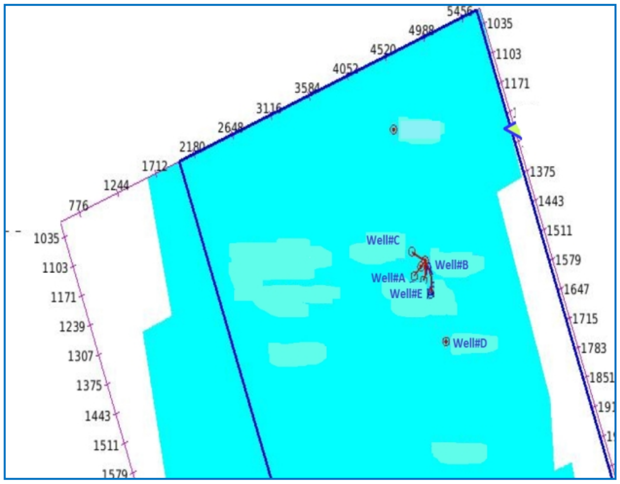

Figure 1: Base map showing location of wells under study

Carbonate rock physics modeling

The carbonate rock physics model (Xu et al., 2009) was formulated by modifying the Xu-White (1995) model originally designed to describe the velocity – porosity relationships of clastic rocks was used in the study. Creation of a rock physics model normally starts from petrophysical analysis (Saberi, 2013). Therefore, petrophysical analysis of five wells was carried out to evaluate clay volume, porosity, Sw and these outputs were used in rock physics modeling to build a valid rock physics model.

In the model, the total pore volume is divided into four pore types: (1) clay-related pores, (2) interparticle pores, (3) microcracks, and (4) stiff pores. From the SEM images as shown in Figure 2 it also evident that the carbonates in the area of study has these different pore types.

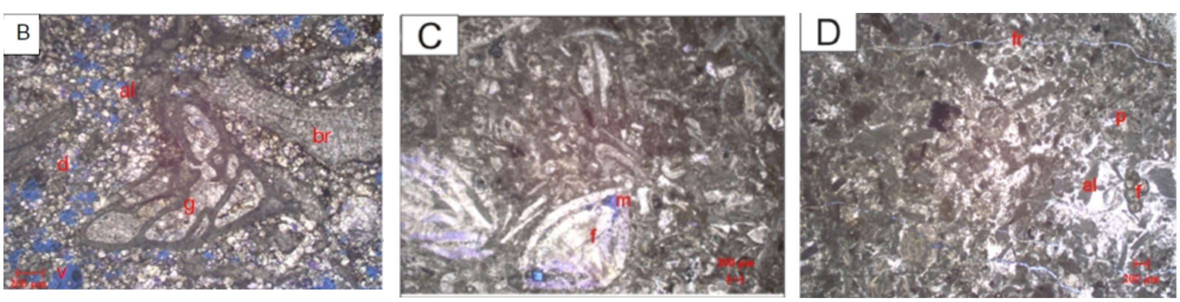

Figure 2: SEM Images of sidewall cores of Well#E showing Vuggs (v), moulds (m), fractures (fr).

The following methodology of Xu-Payne rock physics modeling was followed and Density, Vp and Vs logs were modelled and calibrated in the Well-A, in which recorded shear log data is available. Figure 3 shows how the model works. This method consists of four steps (Xu et al., 2009).

1) The minerals present in the rock are mixed using a mixing law (e.g., the Reuss-Voigt-Hill average). We begin with a solid rock matrix having the properties of this mixture.

2a) Micropores with bound water (e.g., clay pores) are added to the matrix using the differential effective medium or DEM (Xu and White, 1996) process and the Kuster- Toksöz theory (1974) to account for the mechanical interaction between the pores. The calculated effective elastic properties (e.g., bulk modulus) will be used later as the “solid” properties for fluid substitution.

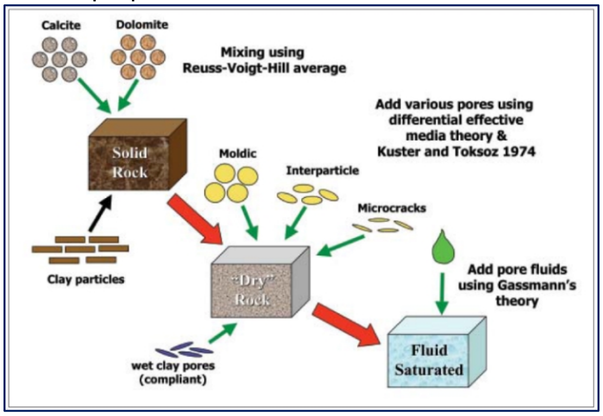

Figure 3: Diagram of carbonate rock physics model. This diagram was taken from Xu and Payne, 2009.

2b) All pores including water-wet micropores and empty (or dry) non bound-water pores are added into the system using the effective medium theory to provide the effective elastic properties (e.g., bulk modulus) of the “dry” rock frame.

3) The remaining water (which is not bound to micropores) is mixed with the hydrocarbons (oil or/and gas) using a fluid mixing law such as the Wood suspension model.

4) Gassmann’s equations are used to add the fluid mixture into the pore system in order to obtain the final effective elastic properties for the saturated rock.

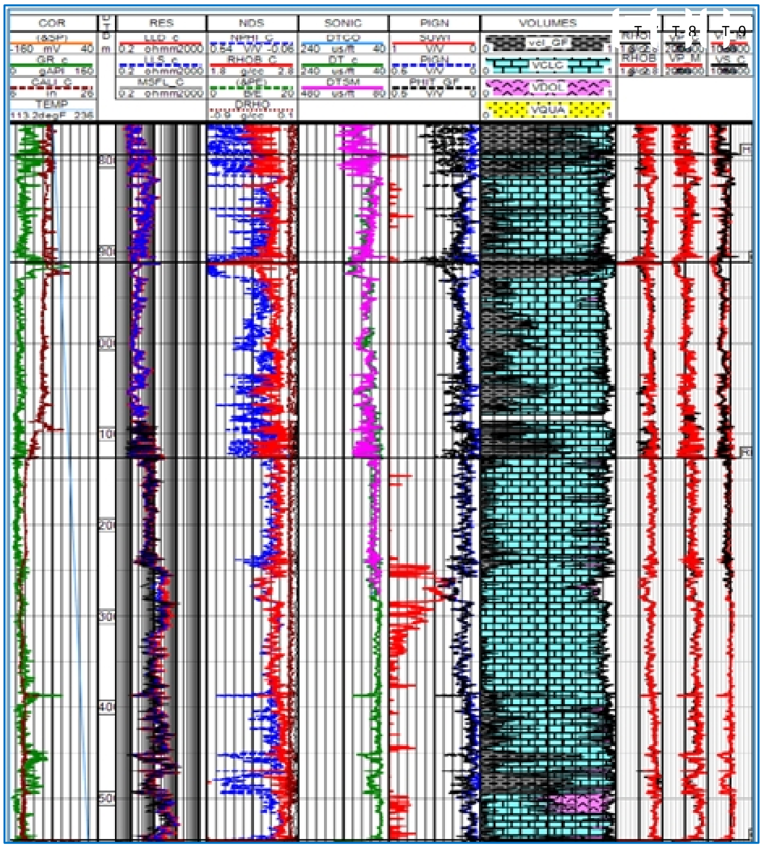

Figure 4: 1D match between recorded and modeled logs of Rhob, Vp, Vs. Red curved in tracks T-7, T-8 & T-9 shows modeled curves and black curves are recoded logs.

Figure 4 show a comparison between the recorded and modeled logs of Well#A. The cross-plot of recorded P-impedance versus Vp/Vs log colored with Litho log doesn't show any relationship whereas modeled logs show a relationship and hydrocarbon zone can be discriminated from other litho-facies as shown in Figure 5 (A&B).The calibrated model is now applied to other wells understudy to model density, Vp and Vs logs, which will be used for well-to-seismic tie and seismic inversion studies. Figure 5(C) displays P- impedance vs Vp/Vs plot colored with facies log of all wells discriminating between Oil Limestone, water bearing limestone and shale.

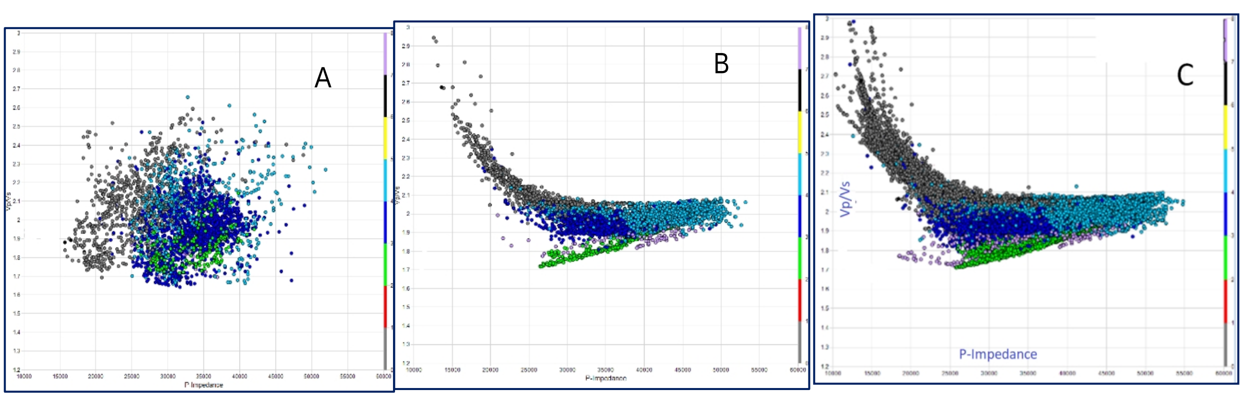

Figure 5: Cross plot of P-Impedance and Vp/Vs ratio. (A) Raw data of Well#A does not discriminates between different facies (B) Model data of Well#A discriminates between hydrocarbon from other litho facies (C) Model logs of Well # A,B,C,D & E discriminating hydrocarbon from other litho facies. Litho

facies codes: 1. Shale, 2. Limestone-Gas, 3. Limestone - Oil, 4. Limestone - water, 5. Limestone - tight, 6.Sandstone, 7.Coal, 8. Limestone – Marginal Oil bearing.

Rock physics to Seismic

Well to seismic tie of 5 RPM wells was done using angle stacks for Pre-stack inversion. Multi-well wavelet has been extracted. Constrained sparse spike inversion algorithm has been applied for inverting the available angle stacks using multi-well wavelet and initial model as inputs (Figure 6). It is possible to discriminate hydrocarbon bearing zone from the cross-plot of P-impedance vs ratio of P-wave velocity to S-wave velocity (Vp/Vs) colored with litho log filtered at seismic band as well as from the cross-plot of inverted P-impedance verses ratio of inverted P-wave velocity to S-wave velocity (Vp/Vs) extracted from inversion volumes at well locations (Figure 7). Figure 8 shows a section display of inverted P-impedance and Vp/Vs passing through all wells highlighting the most probable hydrocarbon polygon zone. This probable hydrocarbon polygon is useful to capture probable geo-bodies .The integrated petrophysical analysis, rock physics modeling and seismic inversion studies has improved the reservoir characterization of carbonate reservoirs.

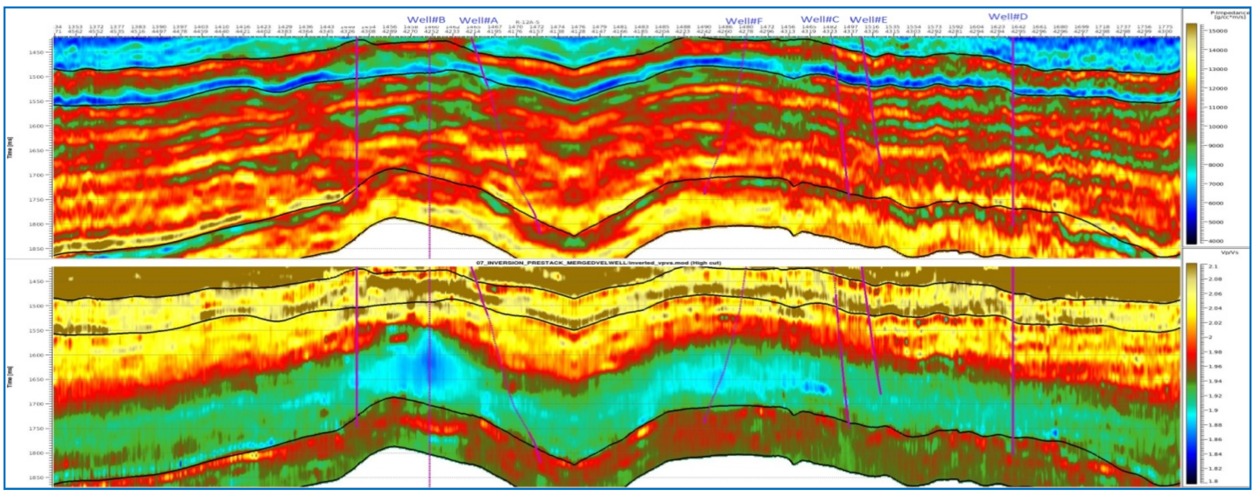

Figure 6: Inversion result along an arbitrary line connecting all wells with P-impedance (Upper section) and (Lower section) Vp/Vs ratio section.

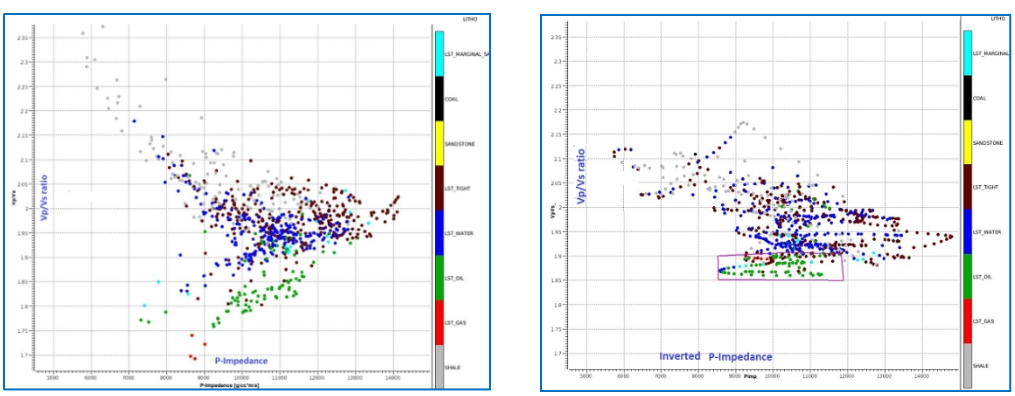

Figure 7: (Left) Crossplot of P-impedance versus Vp/Vs ratio colored with Litho logs. (Right) Crossplot of the Inverted P-impedance versus Vp/Vs ratio extracted at well locations colored with Litho logs highlighting the probable hydrocarbon zone.

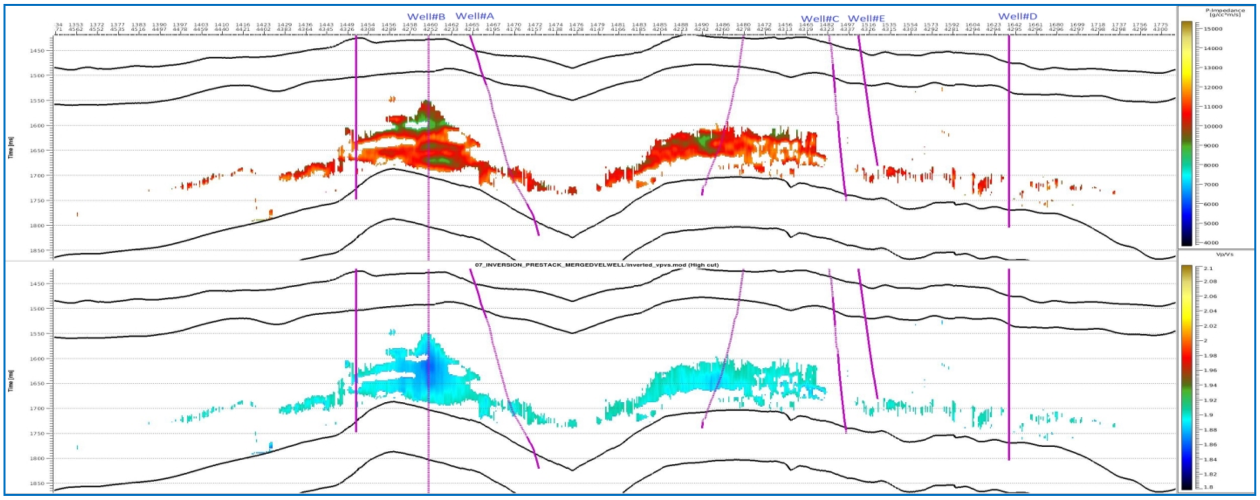

Figure 8: Display highlighting the hydrocarbon polygon on Inverted P-impedance (Upper section) and ratio of P-wave velocity to S-wave velocity (Vp/Vs) sections (Lower section) along an arbitrary line connecting all wells.

Conclusions

In this study, we have applied Xu-Payne carbonate rock physics model which is the extension of Xu-White model to model Rhob, Vp and Vs logs. One of the main challenges of carbonate rock physics modeling is to partitioning the pore space. Based on the core studies and local knowledge of the field the pore space divided into interparticle, vuggy, moldic and fracture pores. Crossplot of P-impedance vs Vp/Vs colored with litho logs from recorded logs does not show any relationship. Using the modeled logs from rock physics modeling probable hydrocarbon polygon can be identified from the crossplot of inverted P-impedance versus inverted Vp/Vs ratio extracted at all well locations. Geo-bodies can be extracted using most probable hydrocarbon polygon, may be indicative of reservoirs. This analysis needs to be combined with other G&G studies to firm up the identified prospects. The integrated petrophysical analysis, rock physics modeling and seismic inversion studies has improved the reservoir characterization of carbonate reservoirs.

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 Dhruvendra Singh, 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 GEOINDIA - 2018.
The views expressed in this paper are solely of the authors and do not necessarily reflect the view of ONGC.

References

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.

Sain, R., Chen, G., Xu, S., Payne, M. A. and Sultan, A. A., 2008, Carbonate rock physics: geophysical and petrophysical pore types of carbonate rocks from an offshore carbonate field: SEG Las Vegas Annual Meeting.

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

Rossebø, H. Ø., Brevik, I., Ahmadi, G. R. and Adam, L., 2005, modeling of acoustic properties in carbonate rocks: SEG/Houston Annual Meeting.

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