PAPER ID 2004583

Study of Log Derived Rock Parameters for Delineating Gas Sands on Seismic Data in Deep Water Blocks of Mahanadi Basin: A Case Study

NK Khatri, NC Mandal, C Mukhopadhyay, S Hazra, A Barua, AK Dwivedi, Jai Nath Ram and RK Sharma
Oil and Natural Gas Corporation, Limited, JeevanBharti Building, NEW DELHI 100001
nkkhatri@hotmail.com

Abstract

Gas strike in Plio-Miocene sands has invoked the exploration interest in the Mahanadi basin. Gas has been biogenic in nature, and only a few sands are charged, rests are either marginally or not charged. The prospective targets supported by the AVO anomaly on seismic data did not prove all the time to be hydrocarbon bearing. Therefore, rock physics study in two of the NELP blocks of the basin, where some wells existed, was taken up to understand the cause AVO anomalies.Rock parameters Ip-Is or Ip-σ (Vp/Vs) or $\lambda\rho-\mu\rho$etc. derived from sonic and density well log data have been studied as their anomalous behaviour with reference to the background trends get translated to AVO anomalies.

Study showed there existed layers with anomalous elastic property alike the gas sand. But these layers cannot be interpreted hydrocarbon bearing on conventional logs. Therefore such layers and gas sands cannot be differentiated from the AVO study of seismic data.

Study further showed layers with anomalous elastic property existed having properties opposite to that of the gas sands. These layers also cannot be interpreted hydrocarbon bearing on conventional logs. Such layers also generate AVO anomaly on seismic data. These layers can be ruled out to be hydrocarbon bearing from AVO interpretation.

Anomalous elastic properties on log curves caused by the presence of the gas in the sand is insensitive to its saturations. Therefore, the targets drilled on the basis of AVO anomalies may also result as marginal gas saturated sands.

In summary, AVO is not the DHI tool for Mio-Pliocene targets in the area. Targets showing AVO anomalies do not guarantee the gas saturations. However, no AVO anomaly guarantees absence of gas sands and therefore such targets can be ruled out for the drilling.

Introduction

Mahanadi Basin is located in the North Eastern part of eastern continental margin of Indian plate. It is situated between Bengal basin towards NE and Krishna Godavari basin to the SW. Well data in the area indicates that the basin fill consists of sediments of Early Cretaceous to Recent. A basaltic lava flow (Rajmahal trap) is present between Early and Late Cretaceous sediments. Middle Eocene carbonate is also a well established litho marker in shelfal part of the basin. The Oligocene sequence, which is absent in the shelfal part, is expected to be present within the block area. Overlying Neogene sequence comprises of clastics in form of channel – levee complexes, fans and mass-transport systems in a deep-sea set-up. Total sedimentary thickness in the block is expected to be more than 6 kms.

Organic shale of Cretaceous to Oligocene age is expected to serve as the source rocks in the basin. Cretaceous and Palaeocene shale in depth range of 3 to 4.5 kms are reported to be matured for oil generation and before this range for the gas generation. The Miocene sediments are also expected to be matured in this part of the basin. Miocene to Pleistocene sequences show development of abundant channel-levy systems and fans on basin floor set-up. The channels are highly meandering and migrating and these channels and fans are expected to preserve the coarser clastics to serve as reservoir facies.

Gas strikes in the Mahanadi offshore basin in Mio-Pliocene sediments have invoked ample exploration interest in the basin. Amplitude anomalies in Pliocene and Miocene sediments showing the channel fan complex morphology mostly have been the target of hydrocarbon exploration and delineation. Gas has been biogenic in nature, and only a few sands are charged, rests are either marginally charged or not charged. The targetedseismic amplitudes showing AVO anomaly did not prove to be hydrocarbon bearingall the time. Rock physics study is carried out over 3D seismic covered areas as the part of productivity assessment of Mio-Pliocene sediments of blocks 98/3 and NEC2002/2 in the deep watersof the basin (Fig.1)

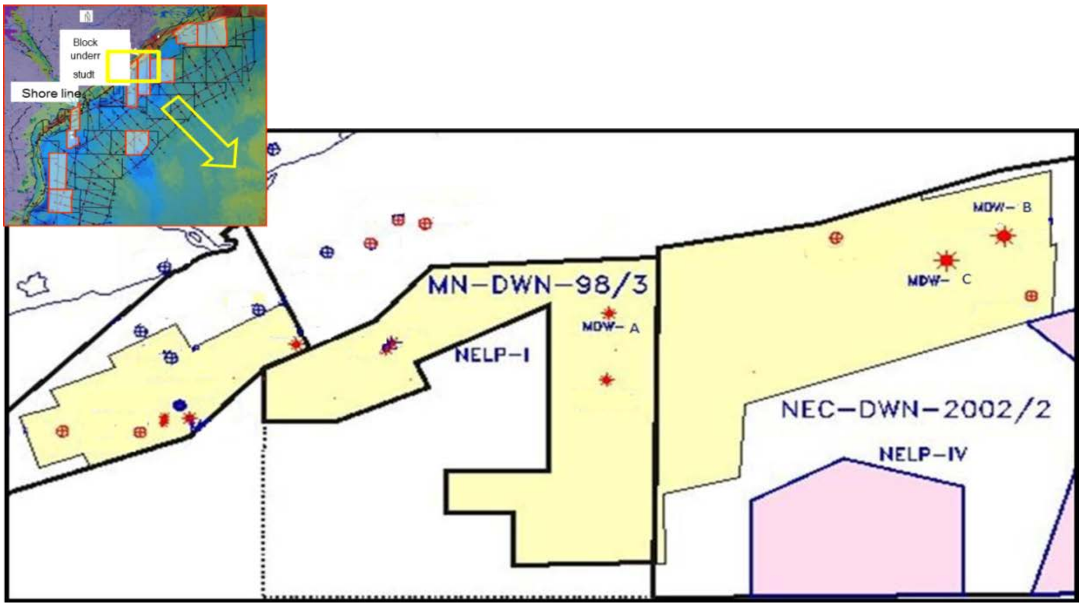

Fig.1: Location map of the study blocks 98/3 and NEC2002/2 showing three well locations MDW-A, MDW-B and MDW-C where the rock parameters are studied.

Methodology:

Rock physics study in two of the NELP blocks of the basin, where some wells existed, had been taken up to understand why all the AVO anomalies generated corresponding to the amplitude anomalies on seismic data do not show up as hydrocarbon bearing. Elastic rock parameter curves viz. Ip-Is or Ip- σ (Vp/Vs) or $\lambda\rho$–$\mu\rho$etc. derived from sonic and density well logs have been studied, as their anomalous behavior with reference to the background trends get translated to AVO anomalies. Conventional logs GR, LLD, NPHI, RHOB and DT for three of the wells viz. MDW-A, MDW-B and MDW-C for the lithology and saturation interpretation and log derived elastic rock parameter curves have been displayed in log curve panels in the appropriate scale to highlight their corresponding anomalous behavior with reference to the background.

- Linear Vp-Vs relation given by the Castagna mudrockline forms the background trends (Castagna, J.P. and Swan H.W., 1997; Castagna, J.P. and Swan H.W., and Foster, D.J., 1998) i.e. increase in Vp/Vs with decrease in Ip and decrease in Vp/Vs with increase in Ip. $\lambda\rho$ and $\mu\rho$ curves moves hand in hand and get closer when higher velocity and lesser value of Vp/Vs and get apart when lower velocity and higher value of Vp/Vs as the background trend, and at higher velocity, $\lambda\rho$ gets close enough to touch $\mu\rho$ or even $\lambda\rho$ crosses the $\mu\rho$ curve.
- Break in linear background relation of Vp - Vs disturbs the Ip - Vp/Vs relationship of going opposite to each other or $\lambda\rho$ - $\mu\rho$ relationship of going hand in hand as the background trends. This results into Ip - Vp/Vs to move in the same direction or reduce the separation between $\lambda\rho$ and $\mu\rho$ as anomalous behavior as compared to the background trends.
- Break in linear background relation of Vp - Vs is more pronounced in $\lambda\rho$ -$\mu\rho$ relationship (Goodway, B., Chen, T., and Downton, J., 1997). The $\lambda\rho$ in the anomalous interval reduces drastically, leading to the lesser separation between the $\lambda\rho$ and $\mu\rho$ as compared to the background trends.
- The Vs calculated from Vp from Castagna transform is named as Vscast and is placed in the same panel with the logged Vs to help highlighting break in linear relationship between measured Vp and Vs through the separation between the logged Vs and Vscast. The Vp/Vscast, $\lambda\rho$cast and $\mu\rho$cast are calculated by substituting logged Vs by Vscast in Vp/Vs, $\lambda\rho$ and $\mu\rho$ respectively. Separation between Vp/Vs and Ip representing the actual trend, and the separation between Vp/Vscast and Ip representing the background trend are placed in two separate panels side by side to highlight anomalous intervals by comparing the separation between the two trends. Similarly, pair $\lambda\rho$ - $\mu\rho$ and pair $\lambda\rho$cast - $\mu\rho$cast are also placed in two separate panels side by side to highlight anomalous intervals more pronouncedly.

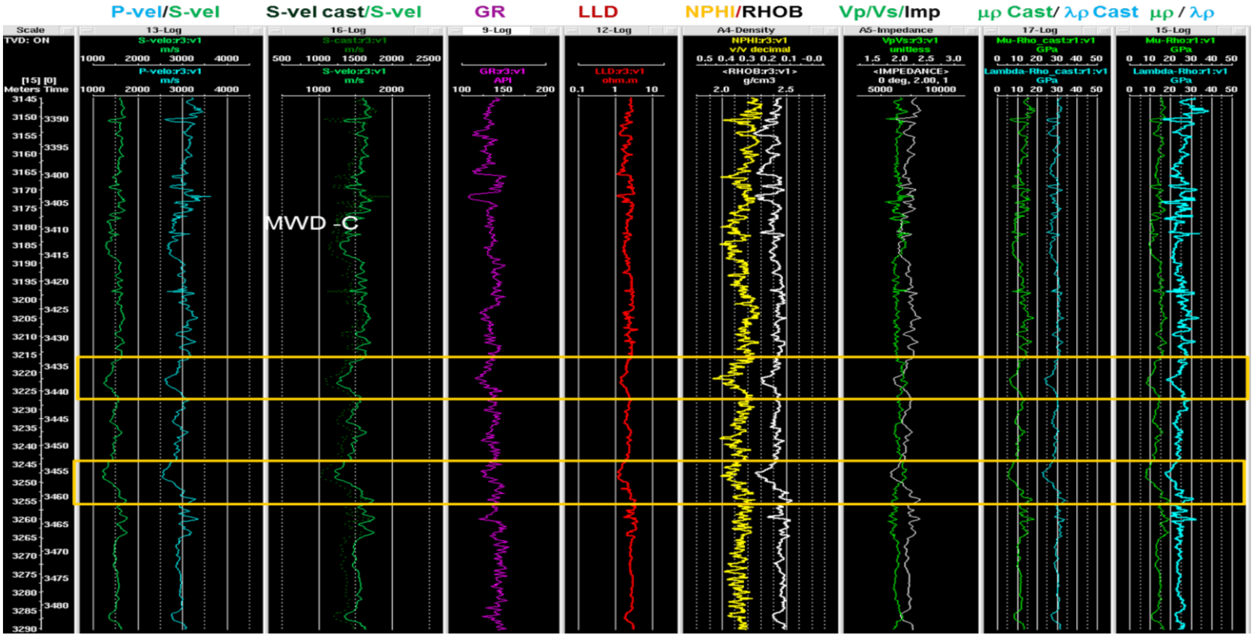

Fig.2 Intervals of low GR, low LLD, well separated High NPHI and low RHOB, low sonic velocity is not anomalouson elastic curves.

- Interval 3225-3230 and 3245-3250 in well-C in Fig.2 are of low GR, low LLD, well separated High NPHI and low RHOB, low sonic velocity in comparison to the over and underlying values. These intervals do not show any anomalous behavior on elastics logs and are not supposed to generate the AVO anomaly on seismic data.

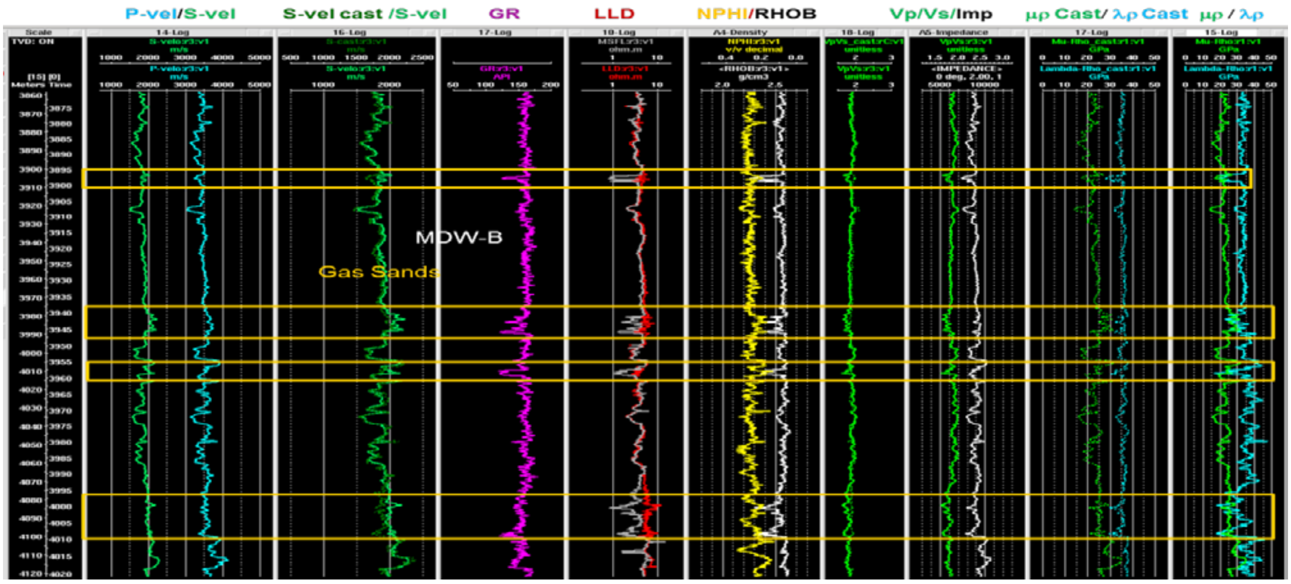

Fig.3 Gas sands have interpreted through conventional logs viz. GR, LLD, NPHI, RHOB. The anomalous behaviour of corresponding intervals on elastic logs is evident.

- Intervals 3980-3988, 4076-78 and 4094-96 in the well MDW-B (Fig. 3) are interpreted to be hydrocarbon bearing with the help of GR, LLD, NPHI-RHOB logs (Figs. 3). Break in the linear trend in the intervals is observed from the separation in Vs and Vscast plotted in the same panel showing Vscast derived from Vp is lower than the logged Vs. Corresponding intervals in Ip-Vp/Vs panel show actual trend deviated from that of background response Ip-Vp/Vscast. Similarly, the corresponding interval in λρ - μρ panels show actual trend deviation in separation when compared with λρcast - μρcast panel.
- Interval 3581-3584m in well MDW-C (Fig.4) is interpreted to be water bearing sand from low value of resistivity combined with interpretation of GR, NPHI-RHOB. The same interval shows break in linear relationship between Vp and Vs and the anomalous behavior in Ip-Vp/Vs and λρ – μρ panels. Interpretation of conventional log and elastic logs in combination, the said interval is interpreted to be marginally gas saturated water sand. Many more such intervals are interpreted in wells MDW-A, B and

C. Therefore such intervals will generate AVO anomaly like gas sand on seismic data, but drilling results will show them to be marginally gas charged sands.

- The upper part of the interval 3885.5 to 3899.5 in well MDW-A (Fig.5) in combination of conventional and elastic logs is interpreted to be gas sand and lower part as marginally gas saturated water sand.

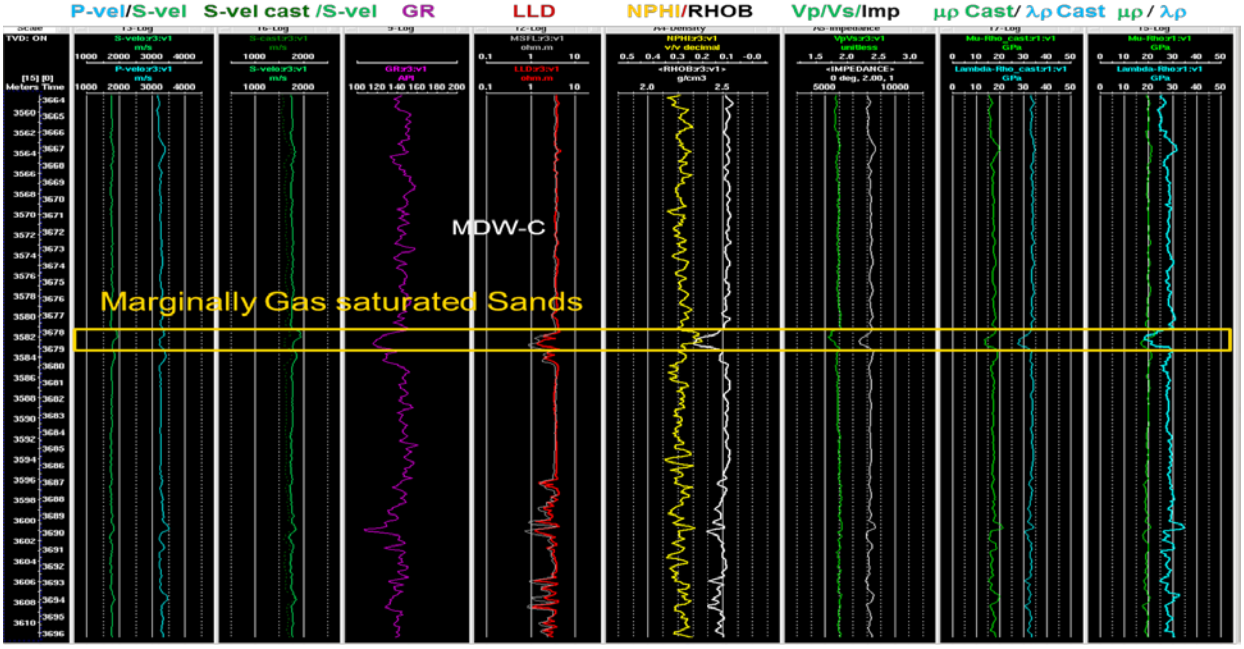

Fig.4 Conventional logs Viz. GR, LLD, NPHI, RHOB have interpreted interval to be water sand.When combined with anomalous behaviour on elastic logs, and the corresponding interval is interpreted to be marginally gas saturated.

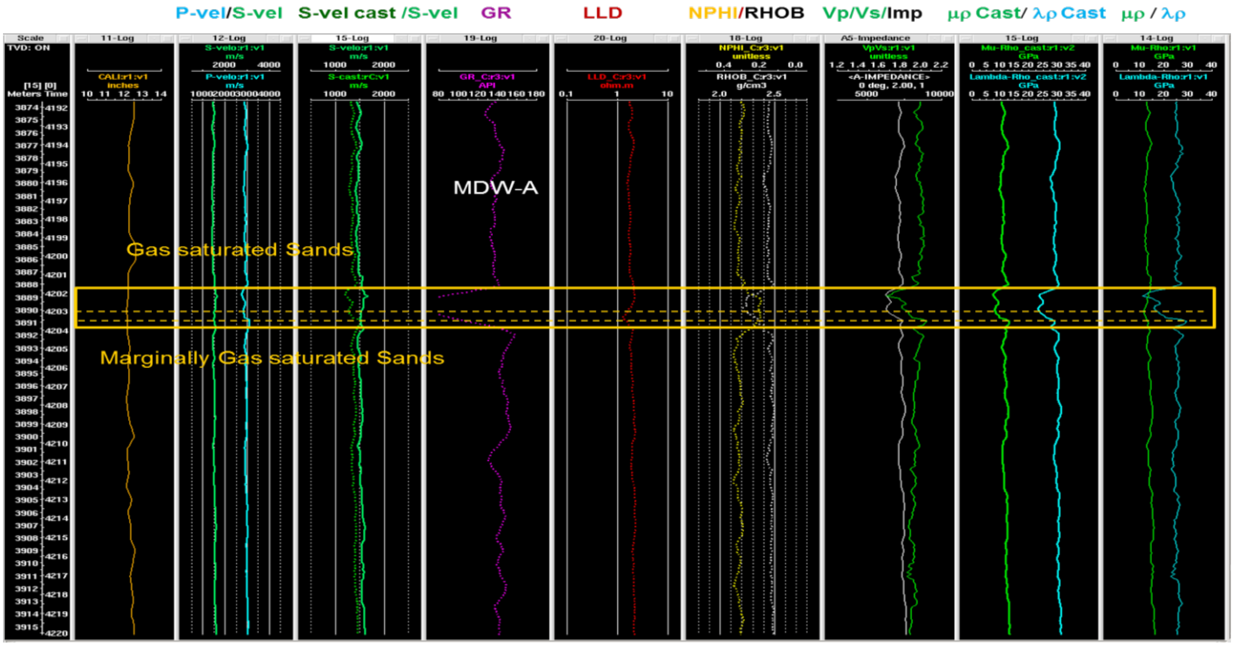

Fig.5 Conventional logs viz. GR, LLD, NPHI, RHOB have interpreted upper part of the interval to be gas bearing and lower part to be water bearing sand and corresponding anomalous behaviour on elastic logs suggest lower part of the interval to be marginally gas saturated.

- Intervals 3442-3467, 3486-3516 and 3533-3562 in well MDW-C in Fig.6 show the break in linear relation between Vp and Vs and anomalous behavior in Ip-Vp/Vs and $\lambda\rho$ - $\mu\rho$ panels and therefore is promising from hydrocarbon point of view, but GR, LLD, NPHI and RHOB do not support the interpretation made from elastic logs. Rather it suggests that there exists some lithology which causes anomalous behavior like hydrocarbon saturated sands on elastic logs. Similarly, Intervals 3350-3360, 3342-3450 and 3515-3530 in well MDW-A (Fig. 7) of area3 of block MN-DWN-98/3 show break in linear relationship between Vp and Vs, the anomalous Ip-Vp/Vs and $\lambda\rho$–$\mu\rho$ relation. Whereas,the GR, LLD, NPHI and RHOB logs do not interpret these interval as the gas sands. Such intervals will generate AVO anomaly like the gas sand and therefore are bound to be interpreted to be gas sands on seismic data.

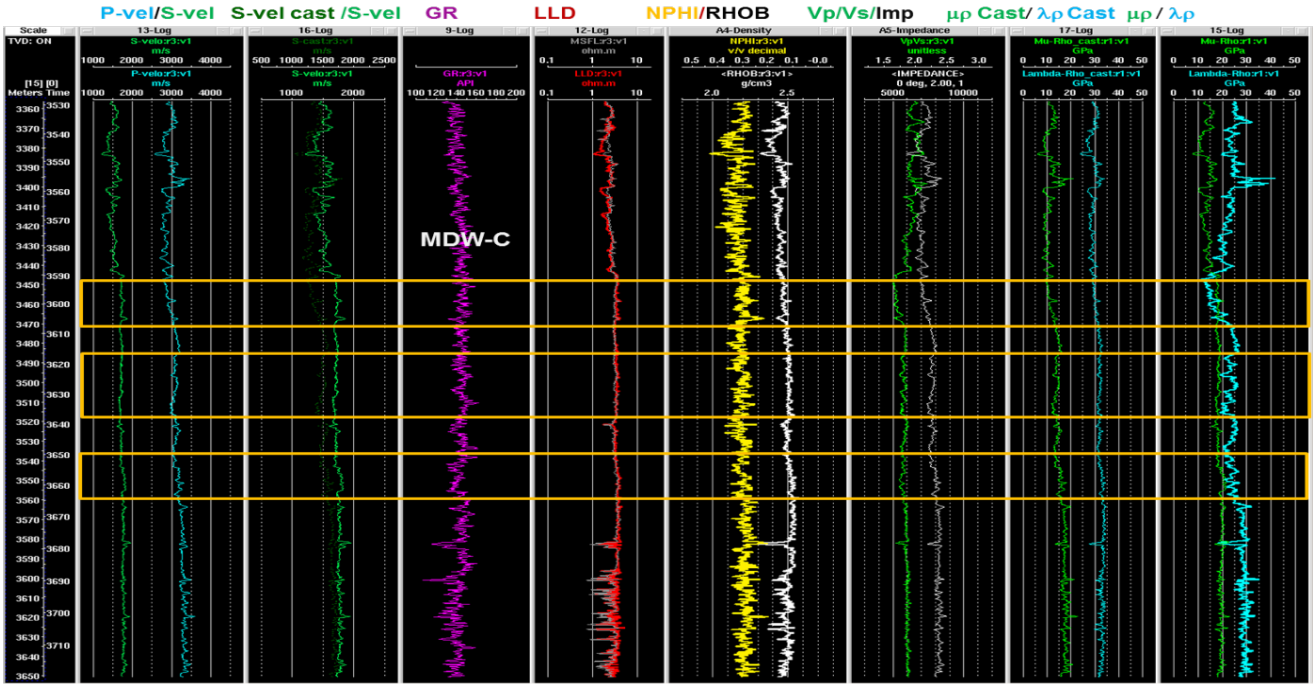

Fig.6 Conventional logs Viz. GR, LLD, NPHI and RHOB do not interpret highlighted intervals to be gas sand and anomalous behaviour of corresponding intervals on elastic logs can be interpreted as gas sands.

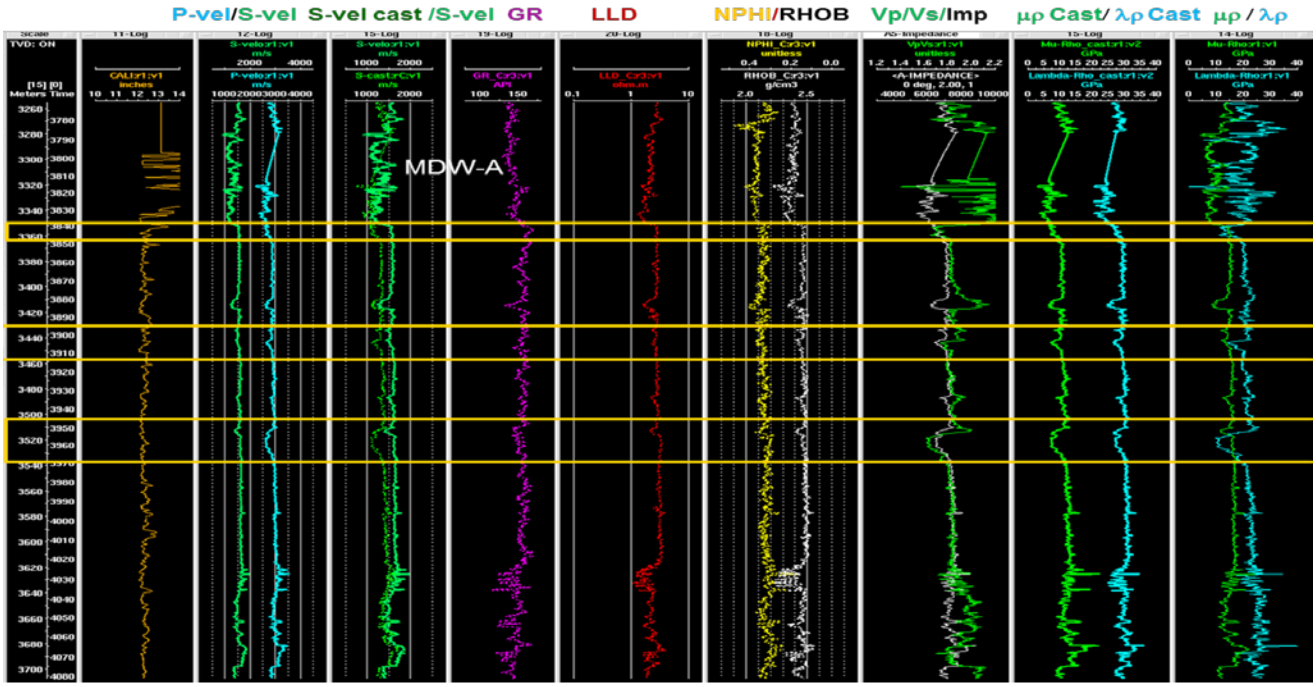

Fig.7 Conventional logs viz. GR, LLD, NPHI and RHOB do not interpret intervals to be gas sand and anomalous behaviour of corresponding intervals on elastic logs can be interpreted as gas sands.

- Interval 2111-2118m, two intervals within interval 2320-2370m each of 10m and interval 2560-2680m in well MDW-C (Fig. 8) show the break in linear relationship between Vp and Vs. Break in linear relationship in these intervals is such that Vscast derived from Vp is higher than the logged Vs i.e opposite to the that of the gas sands case where the Vcast is less than the Vs logged. This case is anomalous behavior of the higher Vp/Vs for higher Ip and higher separation between $\lambda\rho$–$\mu\rho$ in comparison to the background trends. This type of anomalous behavior of rock parameters has not yet been reported to be given by the hydrocarbon saturated rocks. The anomalous relationship between the rock parameters is bound to generate anomalous AVO behavior on seismic data. AVO response generated by such rock parameters is different than the response shown by the gas sands on seismic data and therefore is interpretable as given by the anomalous lithology and not by the presence of gas.

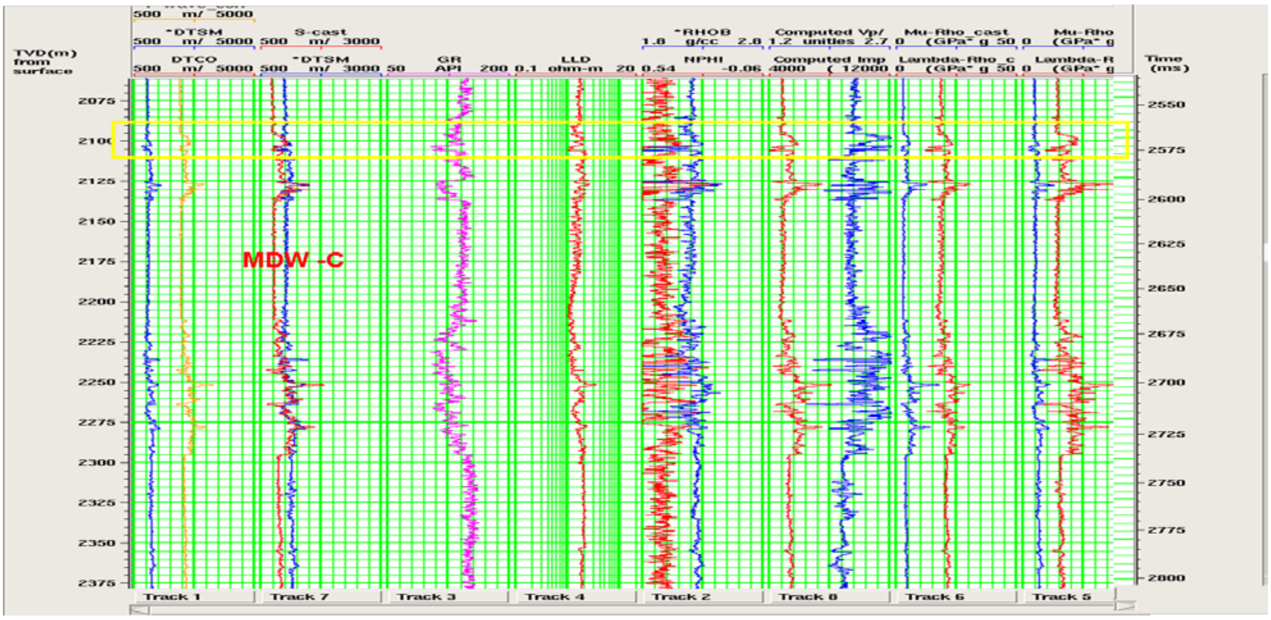

Fig.8 Synthetic and field AVO responses of corresponding interval are highlighted in the rectangle showing increase in amplitude with increase in angle of incidence coming from high impedance layer i.e. inverse behaviour of what is shown as class III type of AVO anomaly by gas sand.

Conclusions:

- Sand layers exhibit anomalous elastic property on log curves irrespective of amount of gas saturations. Therefore, wells drilled on the basis of AVO anomalies may result as marginal gas saturated sands.
- Some of the anomalous intervals on elastic log curves do not interpret as gas sands on convention logs. Therefore, the AVO anomalies show no hydrocarbons on drilling.
- Certain layers show anomalous behavior on elastic properties opposite to that of the gas sands, and do not interpret as gas sand on conventional logs. AVO response of such layers is different than that of the gas sands, therefore can be ruled out to be hydrocarbon bearing on seismic interpretaion.
- In summary, AVO is not the DHI tool for Mio-Pliocene targets in the area as anomalies do not guarantee the gas saturations. However, no AVO anomaly guarantees absence of gas sands and therefore such targets can be ruled out for the drilling.

Acknowledgements:

Authors are thankful to ONGC for permitting to publish the work as the technical paper. Views expressed in the paper are those of the authors only. The paper is part of the project work carried out at ONGC, Kolkata. Authors acknowledge the Director (Expl.), NK Verma, ONGC for the appreciation and encouragement for such study. Authors also express their gratitude to Ex Director (Expl.), SV Rao, ONGC for giving the opportunity to work on the project. Authors are thankful to PK Uphadhayay, IRS,PK Chaudhury, VinodChetia, Geopic& BG Samanta& Team, Mahanadi basin for the technical support through discussions and mapping the anomalies.

References:

Castagna, J.P. and Swan H.W., 1997, Principle of AVO crossplotting: The Leading Edge v.116, no. 4, pp. 337-342.

Castagna, J.P. and Swan H.W., and Foster, D.J., 1998, Framework for AVO gradient and Intercept interpretation: Geophysics, 63, 948-956.

Goodway, B., Chen, T., and Downton, J., 1997, Improved AVO fluid detection and lithology discrimination using Lamépetrophysical parameters; "λρ", "μρ", "l/μ fluid stack", from P and S inversions. SEG Extended Abstracts.

D. J. Foster, and R. G. Keys, Interpreting AVO Responses SEG 1999, Expanded Abstracts

D. J. Foster, R. G. Keys, and F. David Lane, 2010, Interpretation of AVO anomalies, Geophysics, 75, 5A3–75A13. 10.1190/1.3467825.