Study of Log Derived Crossplots for Predicting the Fingerprints of Gas Sands on Stack Seismic Data Through AVO Modeling-A Case Study

N K Khatri[1], Birbal Singh[1], D Srinivas[2] and B S Josyulu[2]
[1]GEOPIC, ONGC, Dehradun , India [2]ONGC, Chennai, India
E-mail : nkkhatri@hotmail.com

Summary

Some of the High amplitude anomalies seen on stack seismic data have proved to be hydrocarbon bearing and other generated due to various other reasons. A study was undertaken on Pliocene sandstone reservoirs in two of the fields in an offshore basin with the objective of finding the fingerprints of hydrocarbon presence on stack.

AVO (Amplitude Versus Offset) has been a primary tool for predicting reservoir rock type and pore fluid content. However the success of AVO anomaly (recognition and validation of an anomaly) is constrained by the rock properties of the reservoir and its surrounding media. Class III and IV AVO anomalies are recognized as amplitude bright spots on stack data, and pore fluid prediction are routinely accomplished by anomaly/background amplitude analysis. For class II anomalies, AVO interpretation of prestack data is often needed to recognize potential reservoir. AVO interpretation in class I environment is difficult (Fred, H. Connie, V. S., Mare, S., 2000) because hydrocarbon presence do not show bright spots or amplitude brightening with source receiver offset.

Plots viz. 1. Mudrock line, 2. Vp, Vs and Poisson ratio against depth and 3. Crossplots between impedance/poisson ratio versus porosity/shale volume with the given fluid type are generated using well log data to recognize type of anomaly and signatures for hydrocarbon. Based on their study, a class III anomaly is recognized for porous gas sands and change of polarity for tight gas sands with increase in offsets (Class II). All other situations existing in the interval viz. brine sands, silty shale/ shaly silt and claystone have higher impedance than surrounding shale and generate +RC from the top and decaying of corresponding amplitude with increase in offset.

Paper comprises of the said study and is the foundation work for recognizing the type of AVO anomaly and the establishing the unique signatures of gas sands on seismic data in this case in the interval understudy. Subsequently AVO modeling was done to recognize the signatures for gas sands and to distinguish it generated from rest of other situations viz. brine sands, silty shales and mudstones on gathers and stack section. The inferences have been confirmed on actual stack seismic data at all the drilled well locations.

Introduction

It has been endeavor of industry to minimize the drilling of dry holes. As drilling in offshore is much costly affairs, it becomes all the way more necessary to make use of Direct Hydrocarbon Indicator (DHI) tools to minimize the failures. Customizing seismic and other geophysical data for studying them as DHI is minor fraction of drilling cost and helps in delineation and development of fields. The failures of strikes in number of wells in the basin has forced to look for finger prints in the data corresponding to hydrocarbon bearing reservoirs in general and gas charged reservoirs in particular. The present work is in this direction covering the producing interval within Pliocene age.

CMP gather shows various kinds of amplitude versus offset behavior. Some events have uniform strength across all the offsets, some decay with offset, some grow stronger with offset and other change polarity as offset increases. For last 22 years, AVO has been a primary tool for predicting a reservoir rock type and pore fluid content. However the success of AVO anomaly (recognition and validation of an anomaly) is constrained by the rock properties of the reservoir and its surrounding media. It is not necessary that gas saturated sands have always to be expressed as high amplitude anomaly on stack seismic data. High amplitude anomaly present in stack seismic data can also be caused by various others situations. Wells A, B, C, D and E having shear wave velocity as the part of log suites recorded (Boyer, S., Mari, J. L., 1997) are distributed over the area and available for plotting and modeling the responses to support the interpretation on actual seismic data.

The following strategy was adopted to fulfill the objective of the study:

- Plotting Mudrock line (Vs against Vp) from well log data to infer the anomalous points against the background corresponding to the hydrocarbon.
- Plotting the rock parameters viz. Vp, Vs, Vp/Vs and poisson ratio from well log data against depth/ stratigraphy to know how rock parameters pertaining to lithology and fluid saturations are related to background shale in depth domains.
- Crossploting impedance against shale volume (Vsh) and effective porosity for a given fluid type to know how they are related.
- Crossploting Vp/Vs against shale volume (Vsh) and effective porosity for a given fluid type to know how they are related.

Plots show a class III AVO anomaly to be given by porous gas sands and class II by tight gas sand. Amplitude decay with increase in offset is predicted for water sands, silty shale/shaly silt and claystones on CMP gathers. Based on the above inferences an extensive AVO modeling was carried out to recognize the signatures from hydrocarbon sands and distinguish it generated from brine sands, silty shales and mudstones on gathers and stack section, and found to be unique for gas sands (Meckel, L.D. Jr., and Nath, A. K., 1977, Neidell, N.S. and Poggiagliolmi, E., 1977) The above inferences have been confirmed on actual stack seismic data at all the drilled well locations. Study is submitted in the form of report

Theory and method

I. Observations and Inferences pertaining to relation of Vp, Vs, Vp/Vs and poisson ratio v/s depth:

Vp, Vs, Vp/Vs and poisson ratio are plotted against depth for all the five wells having shear wave velocity logs with the objective of finding how lithology and fluid saturations related with reference to back ground shale. The following observations are made and inferences drawn on interval ranging from 1900m – 2350m (Figure 1):

- The rock parameter viz. Vp, Vs, Vp/Vs and poisson ratio have gross linear trends with depth which are

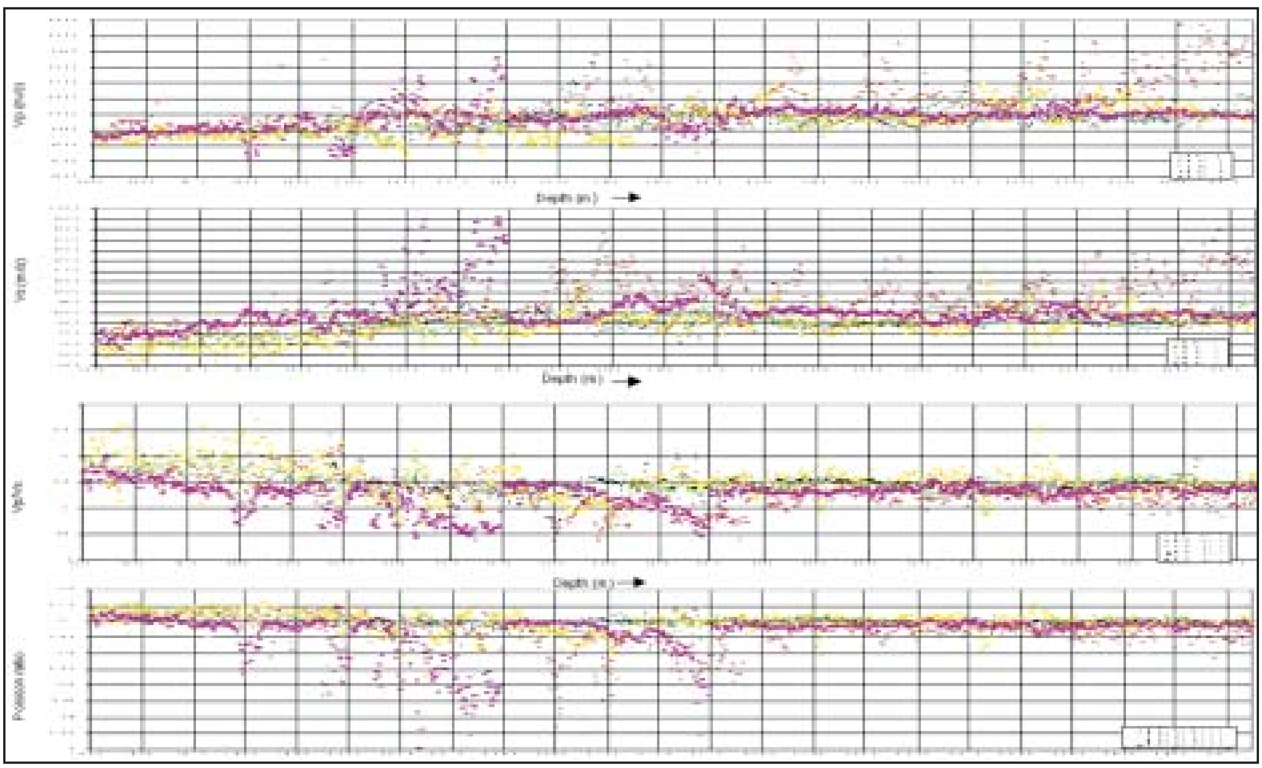

Fig. 1: Vp, Vs, Vp/Vs and Poisson ratio against depth

essentially shale trends. The Vp and Vs increases with depth whereas Vp/Vs or σ decrease. The parameters follow the same trend for all the five wells and their values are quite close with reference to depth.

- Vp/Vs and σ are related to the rock properties in the same way. The deviations of the points falling above the shale trends are enhanced on Vp/Vs v/s depth plot whereas the points falling below the shale trends are enhanced on poisson ratio v/s depth plot. They are the anomalous points responsible for AVO effect.
- At places, Vp and Vs are off the linear trends (Where lithology and/or fluid saturations changed) either in the same or not in the same direction.
- In case of porous water sands and silty shale/shaly silt, both the Vp and Vs are slightly above the shale trends. This results slightly lowering of Vp/Vs then the encasing shale i. e. the corresponding Vp/Vs or Poisson ratio points are slightly below the shale trends in ratio plots. Value of moderate +ve RC from shale sand interface in this case is inferred to decrease slowly with increase in offset.
- In case of tight water sands, Vp and Vs are much above the shale trends and corresponding Vp/Vs or poisson ratio points are comparatively below the shale trends in ratio plots. Value of higher +ve RC from shale sand interface in this case is inferred to decrease comparatively faster with increase in offset.
- In case of tight gas sands, Vp is above and Vs is much above the shale trends and corresponding Vp/Vs or poisson ratio points are much below the shale trends in ratio plots. Value of moderately +ve RC from shale sand interface in this case is inferred to decrease faster and becomes more and more –ve with increase in offset.
- In case of porous gas sand, Vp is below and Vs is above the shale trend, which results in much lessening of Vp/Vs than encasing shale i. e. the corresponding Vp/Vs, or poisson ratio points are much below the shale trends in ratio plots. Value of -ve RC in this case is inferred from shale sand interface to decrease and becomes more –ve with increase in offset.
- In case of marginally saturated porous gas sand also, Vp is below and Vs is above the shale trend which results in much lessening of Vp/Vs than encasing shale i. e. the corresponding Vp/Vs or poisson ratio points are much below the shale trends in ratio plots. Value of -ve RC in this case is inferred from shale sand interface to decrease and becomes more –ve with increase in offset.

II. Observations and Inferences pertaining to relation of Vp, Vs:

Vs on y-axis is plotted against Vp on x-axis (Vp/Vs as color) for all the five wells having shear wave velocity with the objective to infer how their relationship is influenced by lithology and fluid contents (Castagna, J. P., Batzle, M. L., Eastwood, R. L., 1985). The following observations are made and inferences drawn (Figs2 and 3).

Linear regression line fitted best in the plots between Vp and Vs (Mudrock line), which was drawn after deselecting the points corresponding to hydrocarbon sands. It has –ve intercept and + ve gradient, and therefore lesser Vp/Vs for higher Vp.

- It has intercept of ~ -500m/s on Vs as y-axis and gradient ~0.6. Points corresponding to porous water sands and silty shale/ shaly silt are placed slightly above the mudrock line as Vs is slightly higher than for same value of Vp of shale (Figures 2). For all practical purpose they can be taken on the same line. The log curves for corresponding depth interval show the higher value of Vp, higher value of Vs and lesser Vp/Vs than encasing shale.
- Anomalous points corresponding to tight water sands are placed towards higher value of Vp and comparatively little above the mudrock line as Vs is higher than for same value of Vp of shale (Figure 6). The log curves for corresponding depth interval show the higher value of Vp, higher value of Vs and comparatively lesser Vp/Vs than encasing shale.
- Anomalous points corresponding to porous gas sands are placed much above the mudrock line as Vs is much higher than for same value of Vp of shale and decrease in Vp without significantly affecting the Vs and has resulted very less Vp/Vs (Figures 2). The log curves for corresponding depth interval show the lesser value of Vp, higher value of Vs and much lesser Vp/Vs than the encasing shale.
- Points corresponding to tight gas sands are placed towards higher values of Vp and much above the mudrock line as Vs is much higher than for same value of Vp of shale as decrease in Vp without significantly affecting the Vs and has resulted very less Vp/Vs (Figures 3). The log curves for corresponding depth interval show the lesser value of Vp, higher value of Vs and lesser Vp/Vs than the encasing shale.

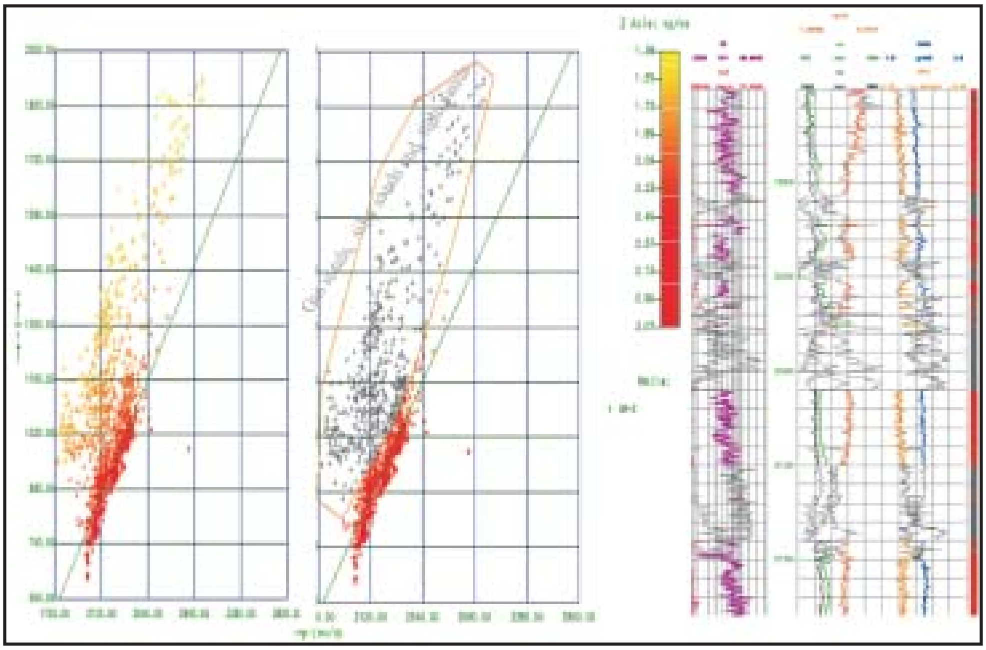

Fig.2: Mudrock line after deselecting points corresponding to porous and tight gas sands. Vp/Vs is in colorbar axis. Deselected points are shown in grey colour on log curve for corresponding interval; Well B

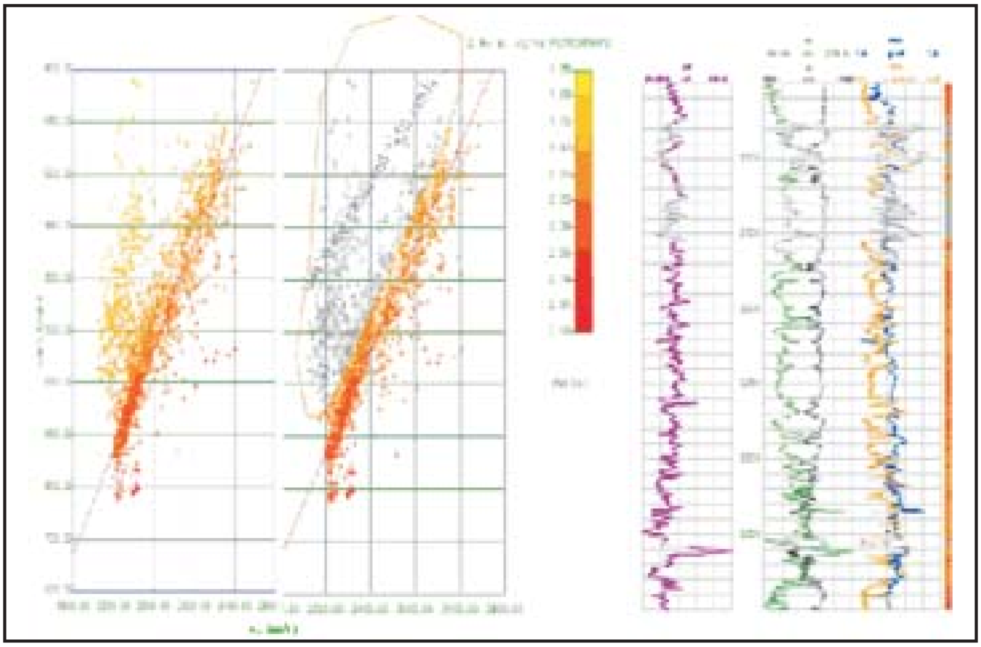

Fig.3: Vs plotted against vp shows the gross linear trend. Linear regression line fits the best after deselecting points corresponding to gas sands, oil and water sands. vp/vs is in colorbar axis. Deselected points are shown in grey color on log curve of corresponding interval. Well B.

III. Observations and Inferences pertaining to rock parameters v/s rock properties:

Generated Xplots with the objective to determine how log derived seismic parameters viz. impedance and Vp/Vs and rock properties viz. shaliness and porosity are related for the given type of fluid saturations in the interval understudy. The density, sonic and sheer velocity logs were edited wherever required with the help of other logs in the suite. The rock parameters viz. impedance and Vp/Vs were calculated from Vp, Vs and density well logs. The rock properties viz. shale volume (Vsh) and effective porosity for water sands were calculated from Neutron porosity and density well logs using mathpack utility of OpenWorks of Landmark softwares. Whereas Vsh for gas sands were inferred from Gamma or SP logs, which was subsequently used for calculating effective porosity from NPHI and RHOB logs. Plotting was done using Xplot utility of OpenWorks of Landmark softwares.

The following observations are made for wells A and D and are discussed for water bearing sand in well A (figure4) and gas bearing sand in well B (figure5).

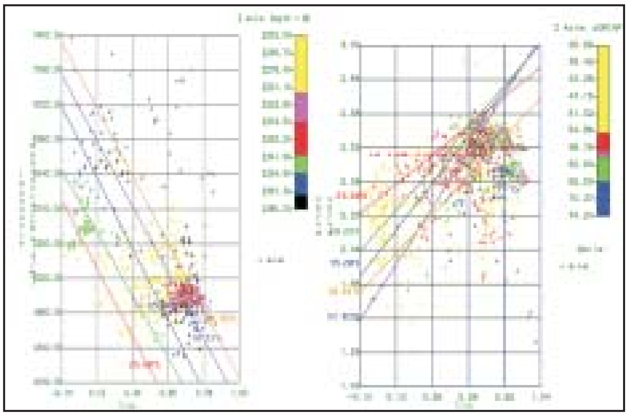

Fig. 4: Impedance and Vp/Vs ratio Xplotted separately against Vsh (shale volume) for water sand keeping true porosity as discriminator. Higher impedance and lesser Vp/Vs of water sand in comparison to encasing shale suggest decay of reflection amplitude with offset. Increase in porosity and shaliness brings down the impedance and brings up the vp/vs ratio close to the shale; Well A

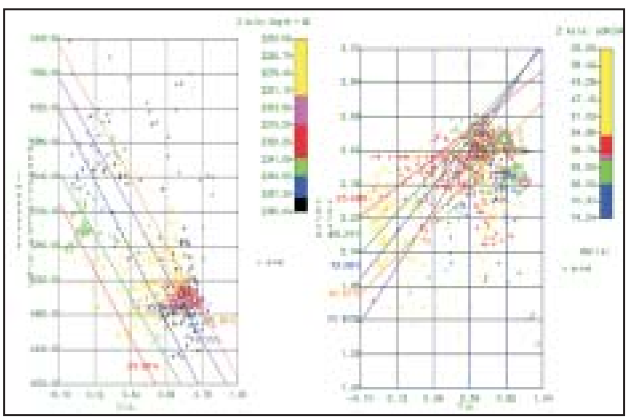

Fig. 5: Impedance and Vp/Vs ratio Xplotted separately against Vsh for gas sand keeping true porosity as discriminator. Lesser impedance and lesser vp/vs of porous gas sand in comparison to encasing shale suggest increasing of reflection amplitude with offset (Class III AVO anomaly). Increase in porosity and shaliness brings down the impedance and brings up the Vp/Vs ratio close to the shale; Well B

A1. Water sands having porosity ~25-30% in well A in the interval of 2253-2380m have equal density and higher velocity than that of encompassing shale and therefore, the higher impedance of sands than shale. It gives rise to Positive RC from shale sand interface and vice versa from sand shale interface.

A2. Decrease in porosity of sand results in increase in density and velocity, therefore increase in positive RC from sand shale interface. The increase in shaliness pulls the above parameters towards the shale parameters, bringing down the positive RC from sand shale interface.

A3. Sand having higher velocity has lesser Vp/Vs (as Vp and Vs being linearly related with +ve gradient and –ve intercept at Vp as x-axis). The decrease in porosity results in increase in velocity therefore further decrease in Vp/Vs for sands and increase AVO gradient w.r.t. overlain shale. Increase in shaliness causes decrease in velocity of sands and therefore increase in Vp/Vs. (towards Vp/Vs of shale) and decrease in AVO gradient.

A4. Silty shale/shaly silt, mudstone have higher Vp and Vs the surrounding shale generating +RC and –Ve difference in Vp/Vs from shale sand interface.

A5. It is inferred from above that + RC generated from shale water sand interface will decrease with increase in offset as Vp/Vs for sand is lesser than shale (Class I anomaly)

Extending the above observations to gas sands interval in wells B (figure5).

B1. Gas sands of ~10% porosity have equal velocity and density that of the shale, and therefore have impedance equal to that of the shale. Increase in sand porosity above 10% results in lesser impedance than encasing shale and –ve RC from shale sand interface, and decrease in porosity below 10% results vice versa. The increase in shaliness pulls the impedance towards shale.

B2. Increase in porosity increases in –ve RC but decrease in gradient, whereas the increase in shaliness will result in lesser RC and gradient (difference in Vp/Vs) from shale sand interface.

B3. As the presence of gas bring down the Vp without significantly affecting the Vs, the Vp/Vs has further lowered, resulting into higher AVO gradient w.r.t. overlain shale than that of the corresponding water sands. Increase in shaliness pulls velocity of sands close to shale velocity resulting in increase in Vp/Vs ratio towards shale and lesser AVO gradient.

B4. It is inferred from above that –ve RC generated from gas sands of more than 10% porosity will decrease (becomes more –ve) with offset as Vp/Vs of gas sand is much lower than that of the encasing shale (Class III anomaly).

B5. Positive RC generated from gas sands of less than 10% porosity will decrease and become more and more –ve with increase of offset as Vp/Vs of gas sand is also much lower than that of the encasing shale (Class II anomaly).

Plots viz.1. Mudrock line, 2. Vp, Vs and poisson ratio against depth and 3. Crossplots between impedance/ poisson ratio versus porosity/shale volume with the given fluid type show a class III AVO anomaly to be given by porous gas sands and class II by tight gas sand. Amplitude decay with increase in offset is predicted for water sands, silty shale/shaly silt and claystones on CMP gathers. Based on the above inferences an extensive AVO modeling was carried out to recognize the signatures for hydrocarbon sands and distinguish it generated from brine sands, silty shales and mudstones on gathers and stack section and found to be unique for gas sands. The above inferences have been confirmed on actual stack seismic data at all the drilled well locations. Study established that in Pliocene depositional setup, the gas sands with reference to background have unique signature. Study has been submitted in the form of report

Conclusions

- Study of anomalous points with reference to mudrock line helped to understand how lithology and fluid saturations affect the AVO.
- Study of Vp , Vs and Poisson ratio agaist depths helped to make out the type of AVO anomaly and the expected seismic expression.
- Impedance and poisson ratio crossplots with Vsh and porosity gave insight what to be expected on gathers and stack section with change in above two rock properties for the given fluid type.
- Above plots combined with AVO modeling recognized the unique signatures for gas sands versus brine sands, silty shales and mudstones on gathers and stack section.

Acknowledgment

Authors are thankful to ONGC for permitting to publish the work as paper. Views expressed in paper are those of authors only. The work is part of the more extensive work (complete with AVO modeling and validation) carried out at GEOPIC, ONGC, Dehradun, India which exists in the shape of report and intended to be submitted for publication in Journal. Authors express their deep sense of appreciation to Y B Sinha, Ex. Director (Exploration) for envisaging the project on DHI. Authors express their deep sense of gratitude and appreciation to S. K. Das, GM-Head, GEOPIC, ONGC and V. Rangachary, GM-Head, INTEG, GEOPIC for providing the opportunity to bring out the work in present shape. Authors are thankful to Dr. C. H. Mehta, Ex ED-Head, GEOPIC and Dr. S. K. Gupta, Ex GM-Head, INTEG for assigning above work to the authors. Authors are also thankful to R. T. Arasu, DGM (S) and P. K. Chaudhuri, C. G. (S) both of ONGC for making themself available for discussions, support and critical comments, which helped us to improve upon during the course of work. Authors appreciate C. Mahapatra, DGM (G) for his interest and encouragement for such studies

The views expressed in this paper are of the author(s) only and not necessarily of ONGC.

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