# Delineation of Miocene Sands by Stochastic Inversion, AVO & Seismic Attributes. A case study from a field in Assam fore-land.

*Ritesh Mohan Joshi, Amrita Roy & Bhaskar Borah*

Ritesh.Joshi@oilindia.in

**Keywords**

Stochastic Inversion, AVO, fore-land

## Summary

The present study covers a Miocene oil and gas field extending over various structures in Assam foreland which is undergoing development. For any developmental project (field), assessment of its hydrocarbon potential and the quantification of the risk associated with it is a much-needed exercise and this field is no different. One of the key elements of this assessment methodology is Stochastic Inversion on Pre-stack time migrated 3D seismic gathers.

Stochastic Inversion methodology applied here, aspires to derive elastic properties, which can then be integrated with other geo-scientific data for delineation of possible extension of hydrocarbon bearing sands. It also aims to minimize the risk associated with the development of Miocene formations. The inversion results were also compared with seismic attributes and the data also underwent AVO studies, the result of which helped fortify the conclusion.

## Introduction

The best 3D reservoir models demand good quality well logs and high-quality seismic data. With no dearth of high-quality seismic data in modern days, 'high - resolution seismic – stochastic – inversion volume' can be easily generated and used as a direct input to the reservoir model. (Chen Xin et al; 2016). The input models for stochastic inversion are built using distributions of earth property models generated from well log data. The inversion usually outputs the average of all the 'good fit' property models but it can output just the single best fit property model. (Cooke, D. & Cant, J.; 2010)

The results shown in this paper are run on a popular geostatistical (single stack & multiple stack) inversion application which is capable of generating high-frequency stochastic models for high-resolution reservoir characterization and uncertainty analysis. The application addresses the band-limited nature of deterministic inversion and helps integrating well and seismic data at a fine scale within a stratigraphic geomodel framework. The advantages of stochastic inversion are its higher frequency nature and the calculation of uncertainty.

Historically, one of the first approach to stochastic inversion was done by Haas and Dubrule, 1994. They used Sequential Gaussian Simulation (SGS) method. Much later Buland & More, 2003 utilized a Gaussian property distribution function to develop a fast approach to stochastic linearized inversion. Doyen et al., 2007 exhibits that combining both Gaussian pdf and SGS approach fetches better and stable results. This project was run on a software which uses Doyen's approach.

**Data availability: Seismic**

An approximate 300 SKM of 36-fold 3D seismic data processed in Pre-STM domain along with pre-stack migrated gathers & seismic velocities were available for this study. Seismic gathers were conditioned for residual noise suppression & flattening of gathers. After conditioning in offset domain, angle gathers were generated using RMS velocity. Three partial angle stacks viz., 14º-23º (near), 21º-33º (mid) & 31º-44º (far) were created from the conditioned angle gathers. Finally, a pre-stack gather was created with mid angles 18º, 27º & 37º for current study. The raw-gathers and results of systematic gather conditioning process is shown in the Figure 01.

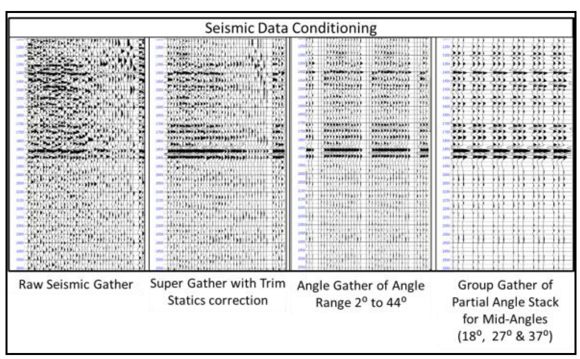


*Figure 01: Conditioning Process and Representative Raw & Conditioned Gather.*

**Data Availability: Horizons**

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Four horizons were used in the study with H1 being the shallowest and H4 being the deepest. The intermediate horizons H2 and H3 forms the upper and lower bounds of the Miocene formation. The study area starts from 100ms above horizon H2 until 150ms below horizon H3. All the horizons with jittery picks (which may create artifact / unrealistic structural pattern in inversion output) were smoothened and horizons gaps were filled (by smoothening filter) (Figure 02).

### Data Availability: Well Logs

Around four wells with full wave sonic logs in the target area were available which were conditioned before the study (Figure 03). Other available relevant datasets include navigation data, formation tops, check-shots, well history & petro-physical interpretation logs.

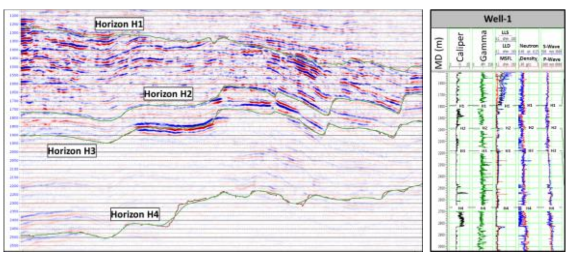
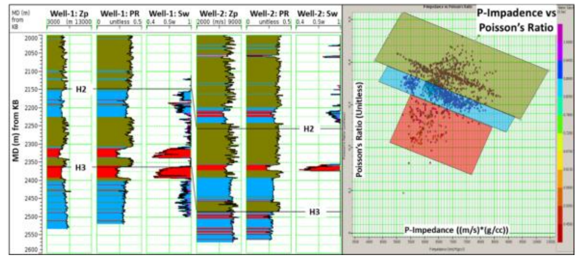



*Figure 02 & 03: Seismic with four Interpreted horizons and conditioned Well Log data of well-1.*

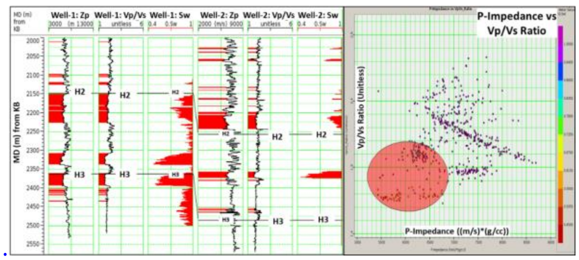
### Data Analysis: Feasibility Study

This study was thus carried out using elastic properties from computed elastic logs (viz. Zp, Vp/Vs, Poisson's Ratio, Lambda*Rho & Mu*Rho) based on which cut-off for the elastic properties were selected to effectively discriminate fluid and lithology within the target formation and map the areal extension of the sand facies within the study area.

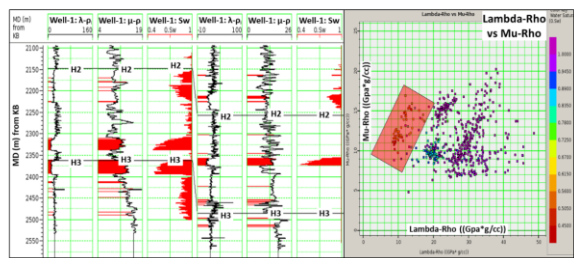
Separation of hydrocarbon bearing sand from the other formation is marked in the cross-plots (Figure 04 a, b & c respectively) between Zp & PR, Zp & Vp/Vs Ratio and λ-ρ & ρ-μ. The feasibility study showed positive results for inversion studies.




a: Cross-Plot between P-Impedance and Poisson's Ratio for two wells. Orange represents hydrocarbon bearing sand whereas light blue represents brine sand.




b: Cross-Plot between P-Impedance and Vp/Vs Ratio for two wells.




c: Cross-Plot between Lambda* Rho and Mu* Rho for two wells.

*Figure 04 a, b & c: Feasibility study to see the sensitivity of hydrocarbon bearing sands from two wells.*

### Methodology

### Well to Seismic Tie

Range limited angle gathers and well-log data were integrated in the inversion study. For this, a group of deterministic wavelets were extracted for three (03) angles ranges (14-23°, 21-33° & 31-44°). A well to seismic tie was then performed at wells.

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### AVO Forward Modelling

AVO forward modeling is carried out in few wells (with full wave sonic and density logs) with a purpose to generate synthetic gather to infer the AVO traits corresponding to the producing hydrocarbon sand. For the analysis of seismic and synthetic gathers, Aki-Richards two term equation is considered for AVO modeling. The well, used for modeling purpose has two sand bodies (lower hydrocarbon producing sand and upper hydrocarbon prospect sand). The AVO analysis (Figure 05 a & b) of the modeled synthetic gathers shows increase in amplitude with increasing incident angles, indicating class III type of AVO response for both hydrocarbon charged sand.

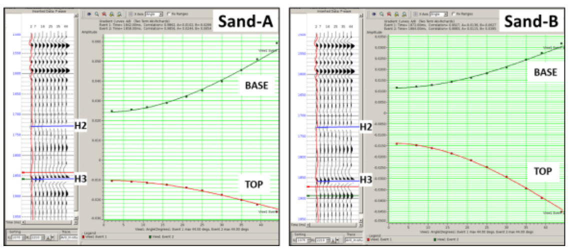


*Figure 05 a & b: AVO Forward Modelling over Synthetic Gather for 02 (Two) hydrocarbon charged Sands (A & B); the increase of amplitude with offset indicates Class-III AVO response for hydrocarbon charged sand.*

### Stochastic inversion Study

Unlike deterministic seismic inversion, the stochastic method accounts for non-uniqueness of the inversion process by delivering multiple realizations that are matched with the available well and seismic data. First, build high-frequency layer model for Zp & Zs using well logs & grid of layers. Second, upscaling statistical group of wavelets to match high frequency model. Third, estimation of correlation coefficient between Zp-Zs within target zone (H2 and H3) from well logs and coefficient for horizon and vertical variograms. (Figure 06). Finally, run Stochastic inversion on a set of partial angles gather stacks over entire volume.

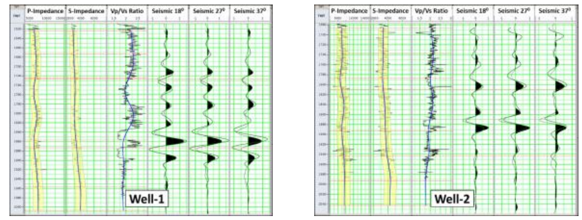


*Figure 06: Results of Inversion Analysis for Stochastic Inversion at Well-1 & Well-2.*

The result of the stochastic inversion i.e. plots of Zp, Vp/Vs, λ-ρ & ρ-μ on a north-south line passing through well-1 is shown in Figure 07a and on an east-west line passing through well-2 & well-3 is shown in Figure 07b.

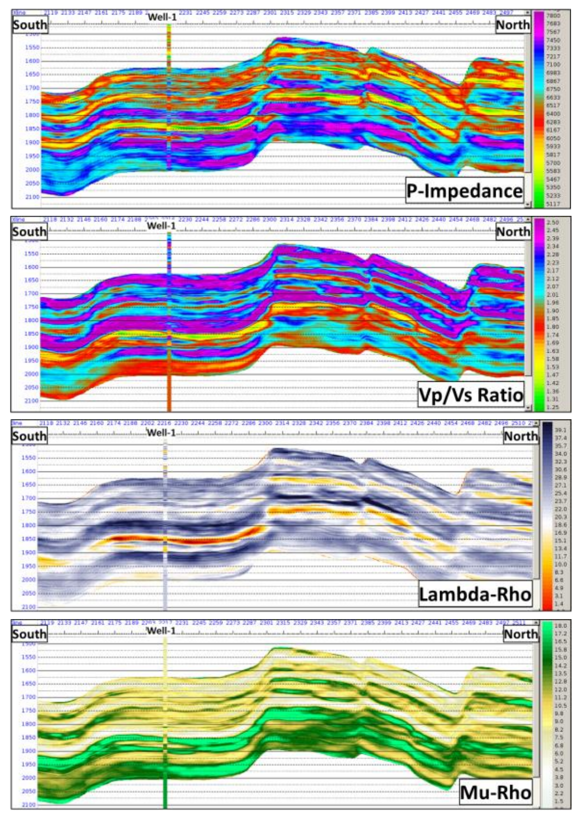


*Figure 07a: Zp, Vp/Vs, λ-ρ & ρ-μ Section along North-South line passing through well-1.*

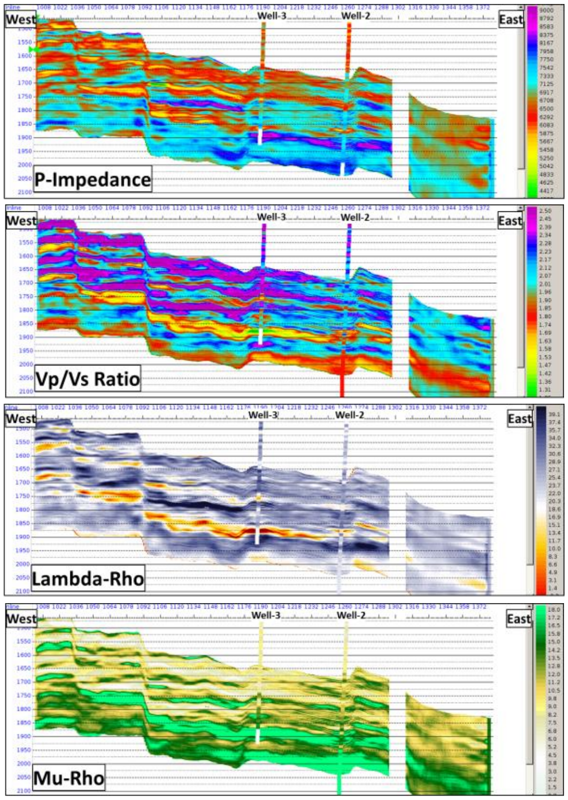


*Figure 07 b: Zp, Vp/Vs, λ-ρ & ρ-μ Section along East-West line passing through Well-2 & Well-3*

One of the objectives of the study was to assess the possible extension of Hydrocarbon bearing sand. To do this a cross-plot between Zp & Vp/Vs was prepared (Figure 8a) and the hydrocarbon bearing sand points indicated by Low P-Impedance and Low Vp/Vs Ratio were demarcated and propagated over seismic section profile which passes through all four wells. (Figure 8b). This profile shows the extension of hydrocarbon bearing sand within the time window 100ms above H2 to 150ms below H3.

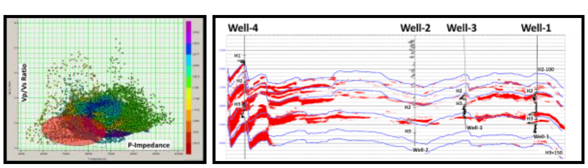


*Figure 8 a&b: 8a: Cross-plot of P-Impedance and Vp/Vs Ratio. 8b: Extension of hydrocarbon bearing sand over an arbitrary seismic section passing through all four wells.*

## Seismic Attribute Analysis

The different attributes derived from seismic data have been analyzed at the target window i.e. the prospective level of H2 & H3 horizons, in order to enhance information about the subsurface and to increase the confidence of the Inversion results. Out of many seismic attributes that were extracted and analysed, Reflection Intensity was found to have strong sync which can be integrated with inversion results to see the possible extension of hydrocarbon bearing sands. Reflection intensity (the average amplitude over a specified window multiplied with the sample interval) helps to enhance the amplitude features keeping the seismic frequency intact. A slice of this attribute is extracted within a time window of 50ms (10ms above H2 to 40ms below H2 i.e. Upper Sand) at H2 prospect level and 30ms time window (30ms above H3 to H3 i.e. Lower Sand) at H3 prospect level and shown in Figure 9.

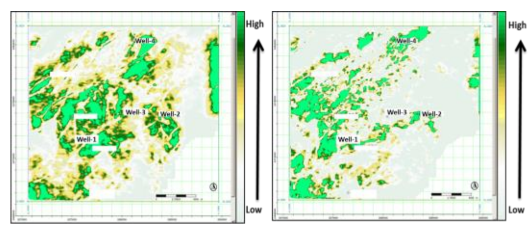


*Figure 9: Lateral extension of possible Hydrocarbon Bearing (Upper & Lower) Sands as seen from Reflection Intensity attribute maps extracted within a target window.*

## Discussion

### Upper Sand: a 50 ms Time Window from 10ms above H2 to 40ms belowH2

Lateral extension of possible Hydrocarbon Bearing Sand as seen from various attribute maps extracted within Upper Sand; a 50 ms time window from 10ms above H2 to 40ms below H2 at H2 prospect level is shown in Figure 10. The attribute maps are (A) Intercept*Gradient, (B) P-Impedance, (C) S-Impedance, (D) Vp/Vs Ratio, (E) Lambda *Rho and (F) Mu*Rho respectively. It is to be noticed that positive Intercept * Gradient (Which marks the presence of Class-III sands) are found to be extended over the time slice. Also, P & S Impedance were found to be anomalous over respective time slices.

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Those anomalies are characterized with low Vp/Vs ratio, low Lambda*Rho and high Mu* Rho values; which are considered to the characteristics of hydrocarbon bearing sands.

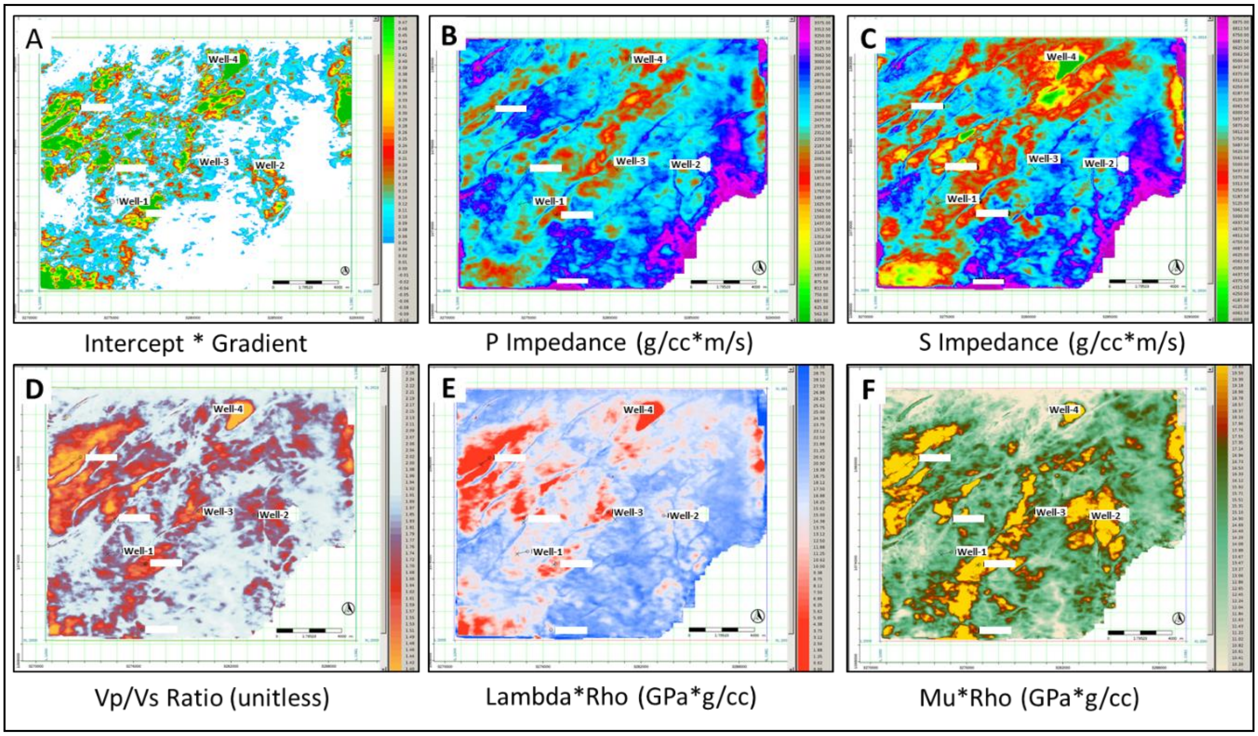


*Figure 10: Lateral extension of possible Hydrocarbon Bearing Sand as seen from various attribute maps extracted within Upper Sand; a 50 ms time window at H2 prospect level.*

**Lower Sand: a 30 ms Time Window from 30ms above H3 to H3**

Lateral extension of possible Hydrocarbon Bearing Sand as seen from various attribute maps extracted within Lower Sand; a 30 ms time window from 30ms above H3 to H3 at H3 prospect level is shown in Figure 11. The attribute maps are (A) Intercept*Gradient, (B) P-Impedance, (C) S-Impedance, (D) Vp/Vs Ratio, (E) Lambda *Rho and (F) Mu*Rho respectively. It is to be noticed here as well that positive Intercept * Gradient (Which marks the presence of Class-III sands) are found to be extended over the time slice. P- & S-Impedance were also found to be anomalous over the respective time slices. Those anomalies are characterized with low Vp/Vs ratio, low Lambda*Rho and high Mu* Rho values; these are considered to the characteristics of hydrocarbon bearing sands.

**Conclusion**

The available seismic & well data was found to be conducive for AVO and Stochastic inversion. Feasibility study provided the range of elastic properties and suggested that the seismic inversion is feasible. The AVO analysis of the modelled synthetic gathers shows increase in amplitude with increasing incident angles, indicating class III type of AVO response for both hydrocarbon charged sands. The Stochastic inversion results i.e. cross-plots and comparisons of slices of various elastic properties for Miocene sands along with slices of seismic attribute suggest possible lateral extension of hydrocarbon. These extensions on vertical profiles validate the results at all three well locations.

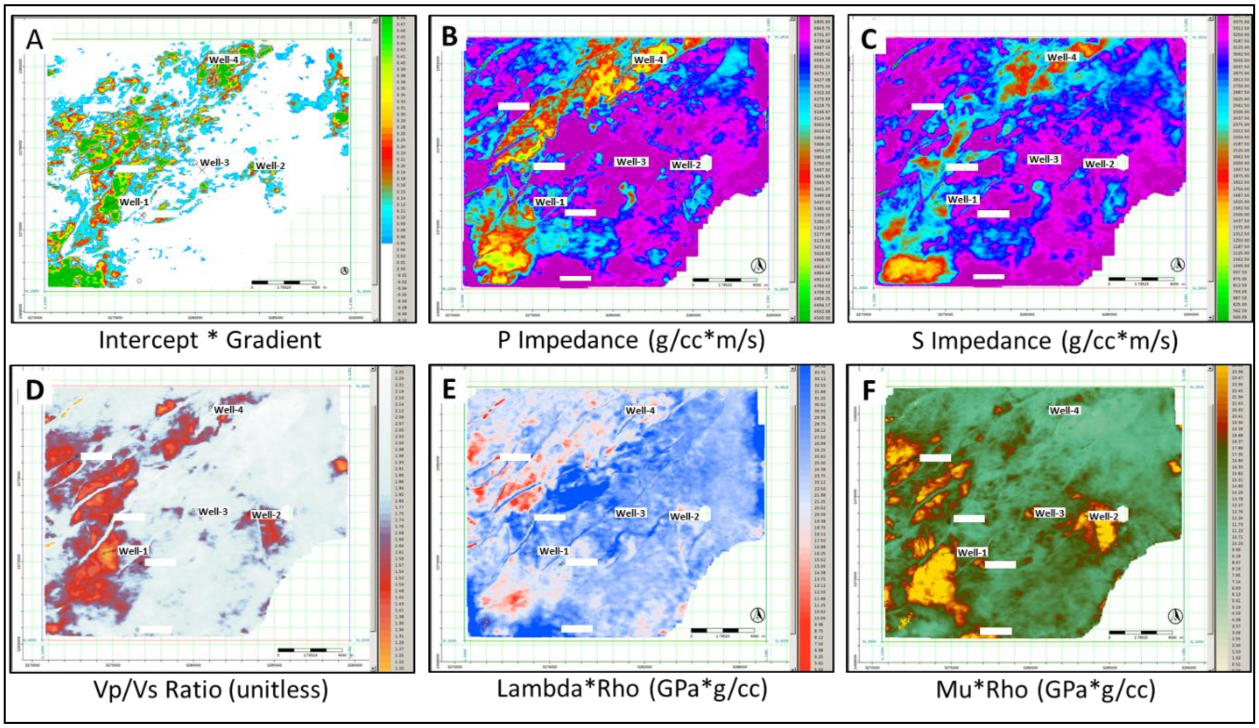


*Figure 11: Lateral extension of possible Hydrocarbon Bearing Sand as seen from various attribute maps extracted within Lower Sand; a 30 ms time window at H3 prospect level.*

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## Acknowledgement

The authors extend their sincere thanks to Oil India Limited management for the permission to publish this work especially Mr. G.V.J. Rao (CGM-Geophysics and Head of the Geophysics department) and Mr. Kanailal Mandal (DGM-Geophysics) for their guidance & support throughout the project. Mr. Anup Kumar (DGM-Geophysics) name requires special mention for his encouragement to write this paper. Thank is also due to Mr. Ashok Kumar (DGM-Geophysics), Mr. Sudhanshu Chugh (DGM-Geophysics) for their critical review and shaping up of this manuscript.