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Application of advance tools for reservoir characterization- EEI & Poisson's impedance: A Case Study

Puja Prakash*, S.K.Singh, Binode Chetia , P.K.Chaudhuri, Shyam Mohan, S.K.Das, *ONGC*

Summary

*Pore fluid and lithology prediction are the two major objectives in any seismic reservoir characterization. In this particular case with limited well control and PSTM data, attempt was made to estimate all feasible petro-elastic and AVO parameters to achieve the objective. Fluid factor, P*G, lambda-rho-mu-rho, Poisson's impedance,* V_p/V_s *are estimated attributes for pore-fluid discrimination of which Poisson's Impedance is found to be providing excellent litho-fluid discrimination. Vclay and porosity are estimated from EEI inversion as lithology indicator. All these attributes put together provided a better understanding of the reservoir quality. However, these need to be supported by other studies from strati-structural interpretation and geological concepts. Here analysis for one particular sequence close to pay level of Well-A have been attempted with this integrated approach.*

Introduction

The block under study is of Mahanadi Offshore basin. The Bathymetry of the block ranges from 925 m to 1575 m. A small portion of block has been recommended to carry out special studies which comprises of an area of 270 km2 (Figure 1). PSTM gather data, RMS velocity field, interpreted horizons and well log data of 2 wells A and B have been used for this study.

Main features of interest are at different stratigraphic levels in Mio-Pliocene sequence. While various quantitative interpretation techniques like AVO modelling, fluid replacement, simultaneous inversion methods have been applied on the existing dataset, the focus of this paper is on the application and results of Poisson's Impedance and Extended elastic impedance (EEI) inversion. Although existing pre-stack inversion techniques are effective in delineating gas sand reservoirs, it is demonstrated through this paper that AI-PI crossplots and EEI are relatively more sensitive for gas sand reservoirs with less ambiguity and uncertainty. However, like all seismic derived attributes, none of these methods are stand alone tools for reservoir characterization and need to be analyzed in integration. Depending upon the quality of available seismic and well data the application of these concepts may vary.

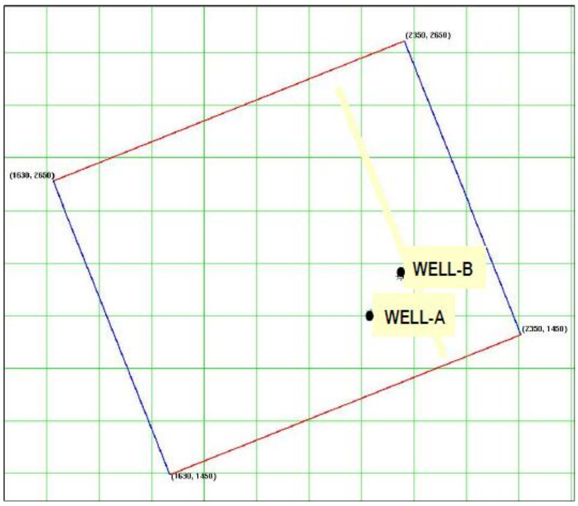

Figure 1:Basemap of Study Area showing Wells A & B.

INTEG, GEOPIC, ONGC, Dehradun
pujaom@gmail.com

Theory and Methodology

Poisson's impedance, PI (Quackenbush et. al, 2006) is a relatively recent concept which incorporates both Poisson's ratio and density information into a single attribute. This parameter optimizes desired separation for different litho-fluid types by choosing an axis of rotation in P-impedance (AI) vs. S-impedance (SI) cross-plot space. In effect,

$$PI = AI - C*SI$$

The constant term **C** optimizes the rotation. As is evident from Figure 2 data clouds are not discriminated along the AI or SI axes alone but with a rotation of the axis represented by the dotted line, the data clouds in this case can be perfectly discriminated.

In the current study PI is found to be providing excellent litho-fluid discrimination (Figure 3&4)

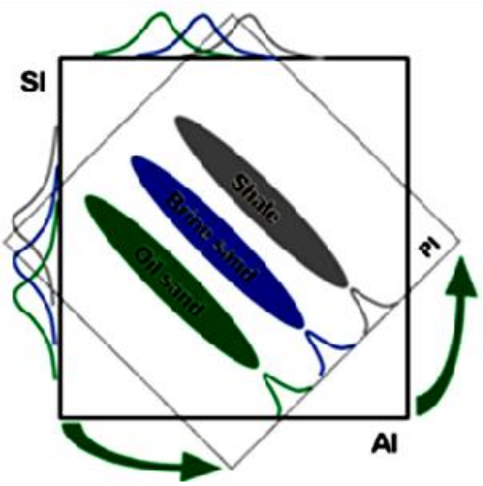

Figure 2: Schematic representation of AI-SI crossplot with shale, brine sand and oil sand distribution. (Quackenbush et. al, 2006, TLE).

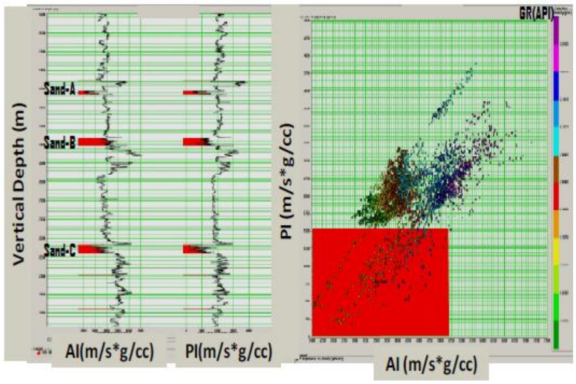

Figure 3: Cross plot between P-impedance and Poisson impedance. Selected zone (red) in cross plot mapped on logs showing gas substituted sand units (A, B & C).

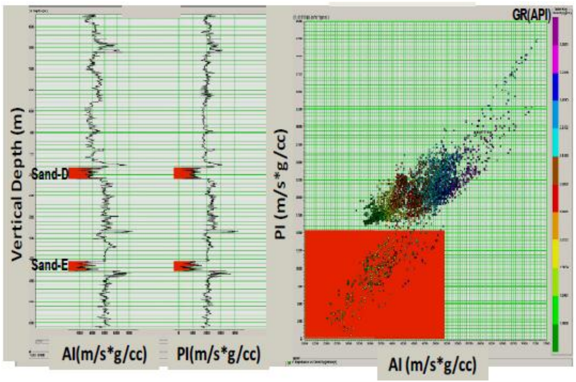

Figure 4: Crossplot between P-impedance and Poisson impedance. Selected zone (red) in crossplot is mapped on logs showing gas substituted sand units (D & E).

P-impedance is more for brine sand and similar for gas sand and claystone (Figure 5). V_p/V_s is less for gas sand and similar for brine sand and claystone (Figure 6). Poisson's impedance of gas sand is less than that of claystone while Poisson's impedance of brine sand is more than that of claystone (Figure 7). Lambda-rho of gas sand is little less than that of claystone whereas Lambda-rho of brine sand is more than that of claystone (Figure 8).

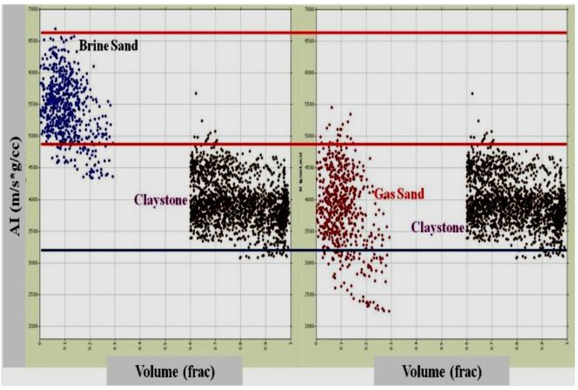

Figure 5: Comparison of P-impedance of brine sand, gas sand and claystone.

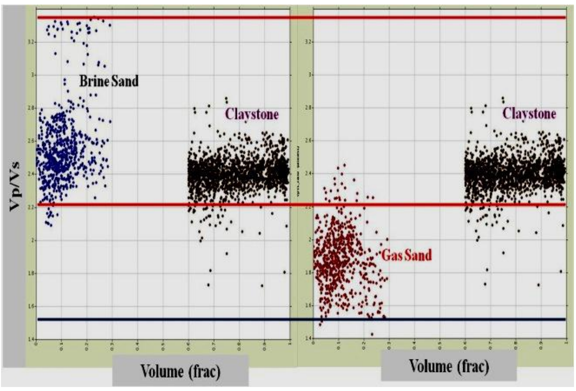

Figure 6: Comparison of Vp/Vs ratio of brine sand, gas sand and claystone.

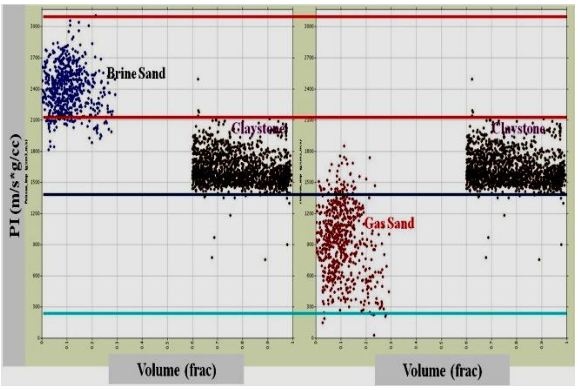

Figure 7: Comparison of Poisson impedance of brine sand, gas sand and claystone.

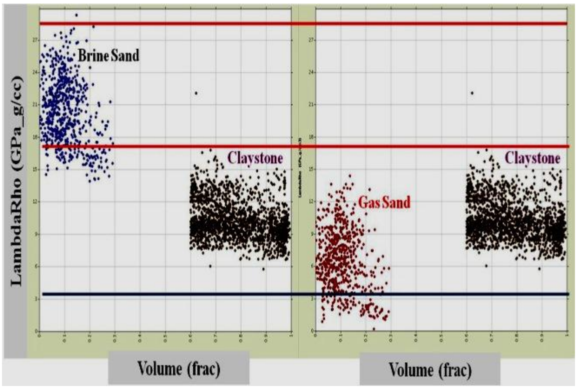

Figure 8: Comparison of $\lambda\rho$ of brine sand, gas sand and claystone.

AI-PI combinations appear to be more sensitive for litho-fluid discrimination. Poisson's Impedance (PI) alone is a very good discriminator of pay sands in this case.

Extended Elasticimpedance (Vclay & Porosity)

Extended Elastic Impedance provides a framework to work with pre-stack AVO but in terms of impedance instead of reflectivity. For the EEI analysis, EEI logs are generated for each well as a function of angle χ and correlated with the target petro-physical logs. For each petro- physical log, cross-correlation of EEI logs at different angle is computed and a plot is then made for the correlation coefficient as a function of angle. EEI can be defined as:

$$EEI(\chi) = \alpha_o \rho_o \left[\left[\frac{\alpha}{\alpha_o}\right]^p \left[\frac{\beta}{\beta_o}\right]^q \left[\frac{\rho}{\rho_o}\right] \right]^r$$

where

$p = (\cos\chi + \sin\chi)$

$q = -8K \sin\chi$

$r = (\cos\chi - 4K \sin\chi)$

α is P-wave velocity, β is S-wave velocity and ρ is density of the media

αo, βo, and ρo are the average of the respective property used as normalization factors for P- velocity, S-velocity, and Density respectively. K is the average of $(\alpha/\beta)2$ in the time/depth interval. The EEI logs at different angles χ correspond to different rock properties. (Whitecombe et. al, 2002).

Work Flow

Flowchart for process of generation and analysis of EEI is shown in Figure 9.

Step 1: EEI logs for χ = -90 to +90 deg. was created using P-wave, S-wave and Density logs by using above formula. (Figure 10).

Step 2: Cross-correlated EEI logs with Gamma Ray, Porosity and Vclay logs.

Step 3: Cross plotted χ angles vs. Cross- correlation coefficient for the targeted rock property logs with EEI logs. (Figure 11)

Step 4: The targeted parameter reflectivity volumes were computed using the Intercept (A) & Gradient (B) AVO attribute volumes with formula at the angle of maximum correlation (χ):

$$\mathbf{R(\chi) = A + B \tan\chi}$$

The volumes created are Porosity reflectivity and Vclay reflectivity. Gamma ray could not be generated with acceptable correlation coefficient.

Step 5: These reflectivity volumes were inverted to estimate Vclay & porosity volumes. (Figure 13 & 14 respectively).

Figure 15 & 16 shows a match between original Vclay and porosity logs with respective EEI computed Vclay and porosity at well-A & B respectively. Vclay and Porosity distribution near Well-A pay and deeper level are shown in Figure 17 & 18 respectively.

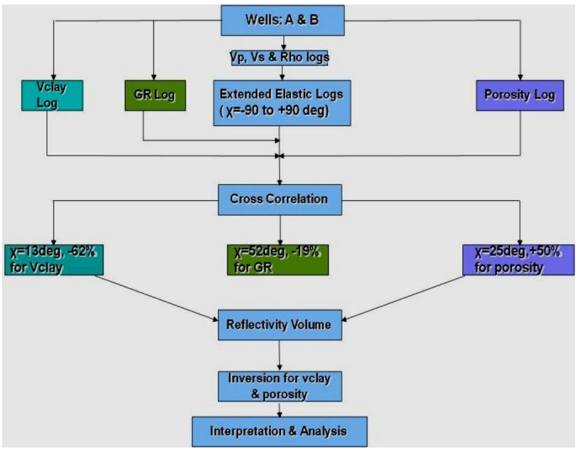

Figure 9: Description of flowchart here.

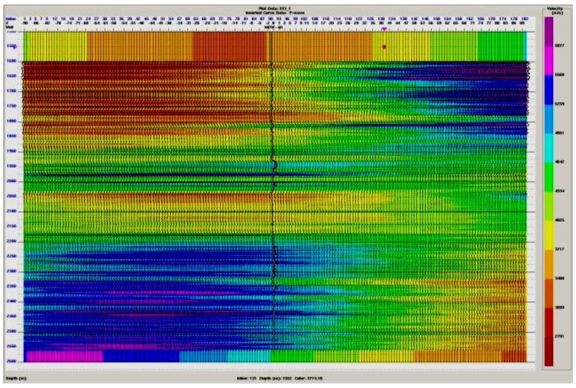

Figure 10: Extended Elastic Impedance (EEI) logs are created for each χ value with P-wave, Density, & S-wave logs for Wells-A & B.

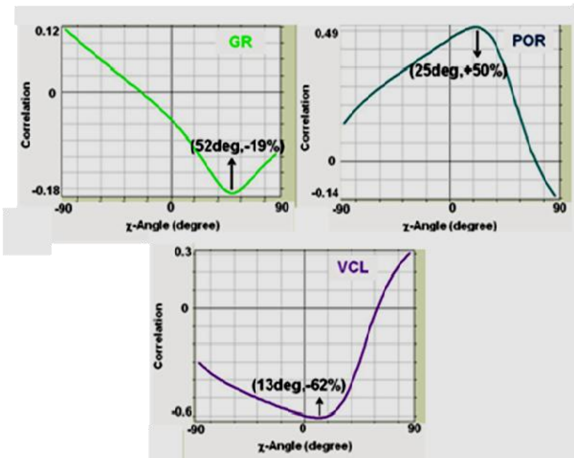

Figure 11: Cross Plot showing the maximum correlation coefficient angle for Gamma Ray, Porosity & VClay logs.

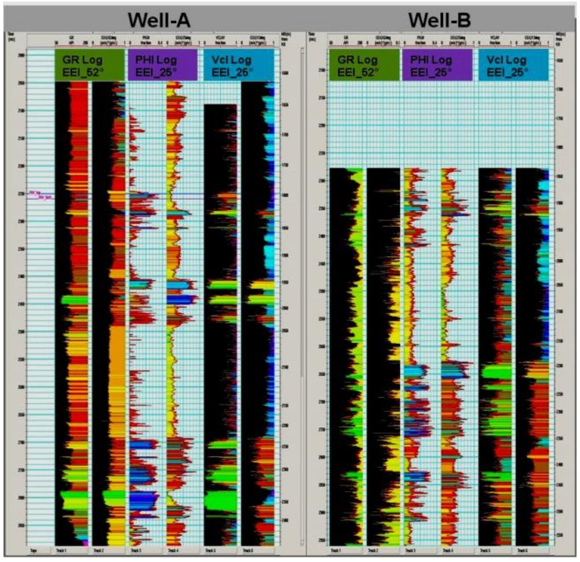

Figure 12: Display showing the correlation between GR, Vclay, Porosity and respective maximum correlated EEI logs for Well -A & B.

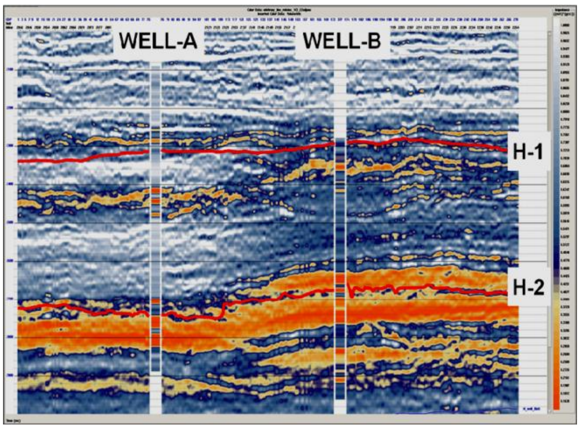

Figure 13: Inverted Vclay section through both the Wells-A& B (Vclay logs overlaid).Approx 15-35% Vclay value observed in pay zone.

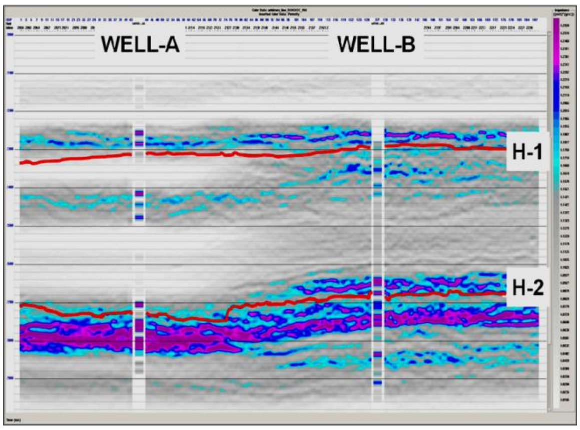

Figure 14: Inverted Porosity section through both the Well-A & B (Porosity logs overlaid). Approx 15-25% porosity observed in pay zone.

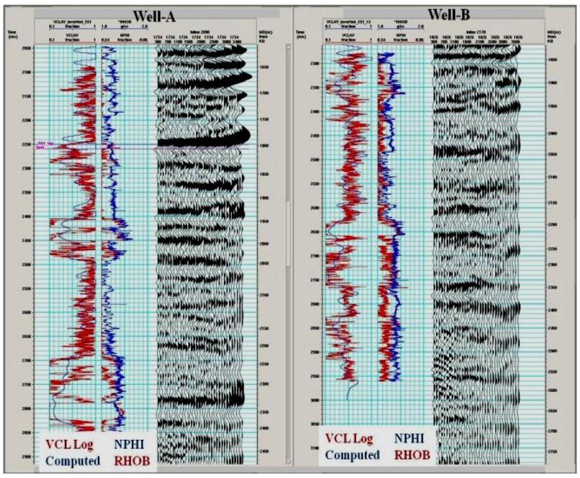

Figure 15: Display showing the match between Original Vclay (red) and inverted Vclay (blue) logs for Well-A & B.

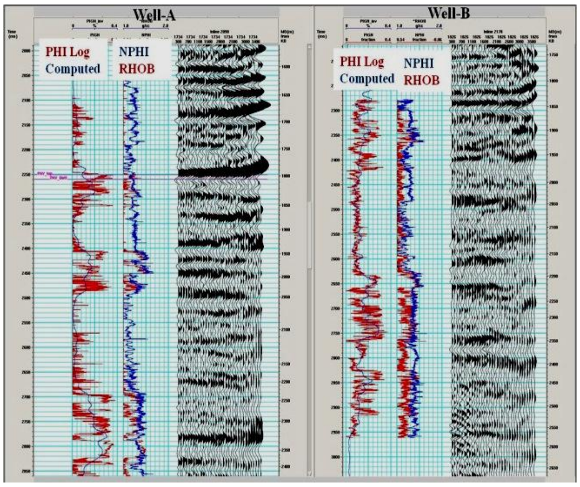

Figure 16: Display showing the match between Original Porosity (red) and inverted EEI Porosity (blue) logs for Well-A & B.

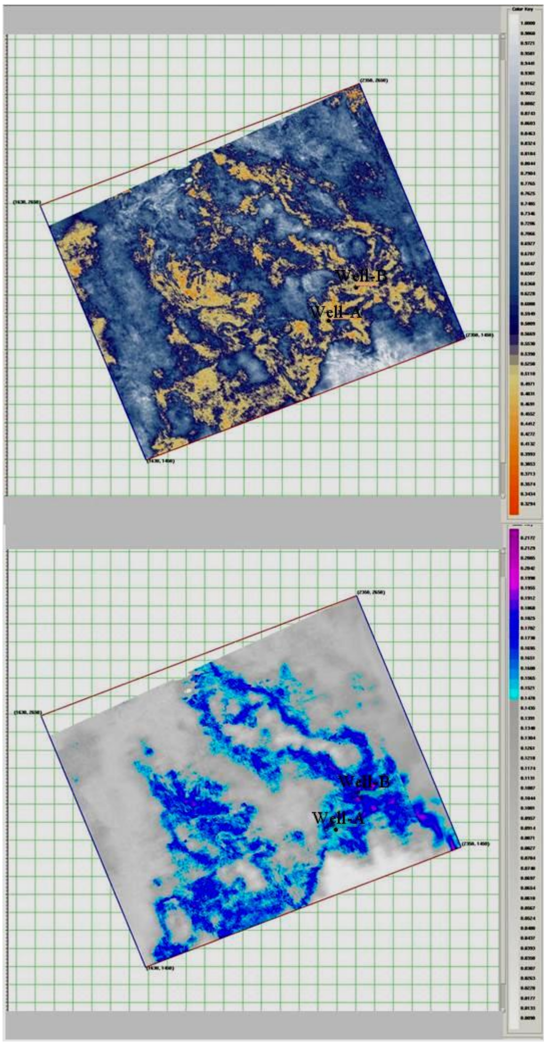

Figure 17: Vclay & Porosity Distribution Slices at shallower (Well-A) pay level with 30ms window above horizon H-1 minus 15ms.

Results

For fluid discrimination, Poisson's impedance (PI) appears to be relatively more effective for delineating gas sand reservoirs in comparison to AI, Vp/Vs and $\lambda\rho$. Results of estimated Vclay and porosity from EEI are to be used with reservation as the certainty is not more than 50-60% as mentioned earlier.

Integratedstudy with all these attributes indicates that in the sequence close to well-A pay, although sand fill channels are observed with good porosity development, characteristics of pay sand is observed to be limited primarily in and around well-A towards south-east of the area and also in a limited area towards south- west as shown in Figure 19 with all the slices for this sequence.

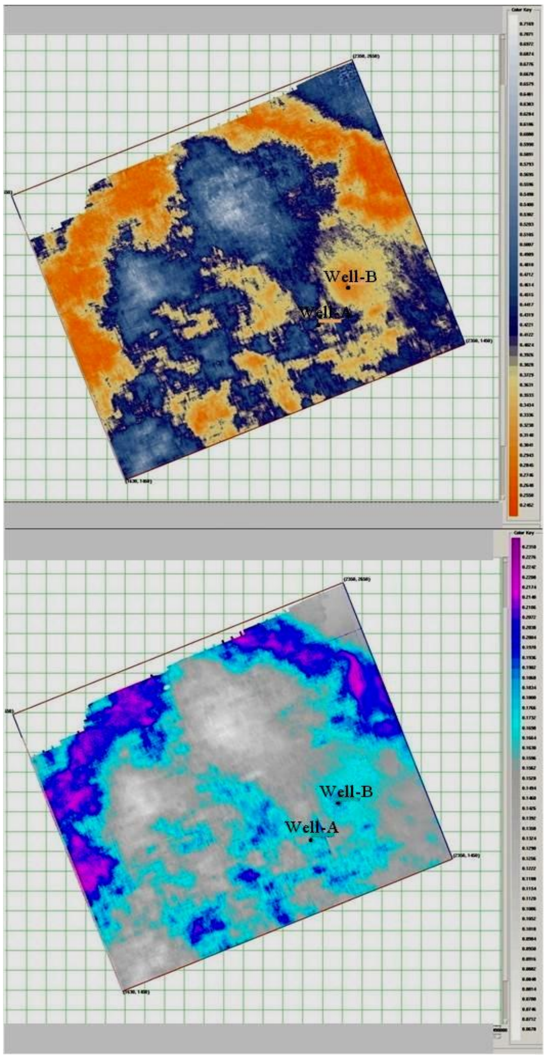

Figure 18: Vclay & Porosity Distribution Slices at deeper(Well-B) pay level with 60ms window centred horizon H-2.

Deeper level sand fill channels are observed with good porosity but probable pay sand characteristics are also observed to be not large in areal extent near well-B from inversion and AVO studies, Figure 20. All these attributes put together provides a better understanding of the reservoir quality as shown in Figure 19 & 20. However, these need to be supported by other studies from regular interpretation and geological concepts.

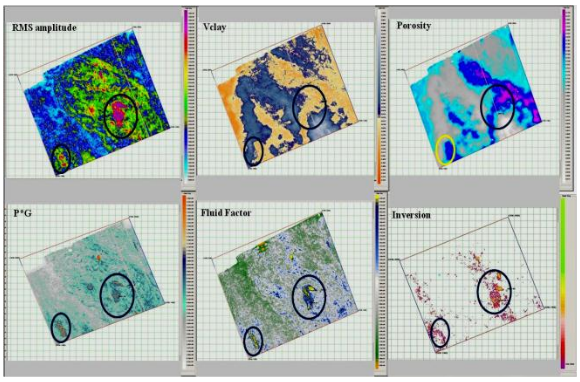

Figure 19: Slices of seismic amplitude, Vclay, Porosity, P*G, Fluid factor and Pre-stack inversion results close to well-A pay level with 60ms centered window horizon H-1.

Conclusions

In order to mitigate risk and reduce uncertainties arising out of several factors in seismic exploration, it is always recommended to assess the prospect with multiple attribute analysis. In this particular case with limited well control and PSTM data attempt was made to estimate all feasible petro-elastic and AVO parameters to achieve this objective as described above.

Fluid factor, P*G, Pre-stack inversion results in combination with Vclay & porosity derived from EEI have been used for integrated analysis mainly in three different sequences within Mio- Pliocene e.g. close well-A pay level, a level much shallower than this and a deeper level. Well logs are not available in shallower and deeper level than these and hence all the attributes related to inversion and EEI were not possible to be estimated.

Due to several uncertainties involved in this kind of analysis, it is always recommended to combine this with the results of regular interpretation studies and geological concept to substantiate the prospects and to make it more robust.

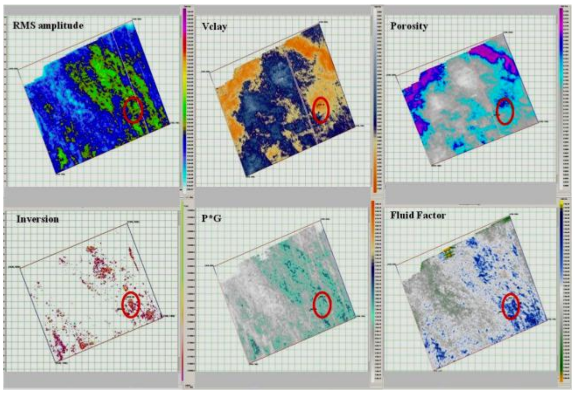

Figure 20: Slices of seismic amplitude, Vclay, Porosity, Pre-stack inversion, P*G and Fluid factor results at deeper level close to well-B pay with a 60ms centered window horizon H-2.

Reference

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