PID : 2010580

Characterizing Shale-Rich Reservoir Using Simultaneous Inversion: A Case Study in Cambay Basin

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Abstract

The paper brings out results of simultaneous inversion for identifying area of "sandy" facies in dominantly argillaceous reservoir unit having potential hydrocarbon interest.

The algorithm involves simultaneous inversion of 3D pre-stack time migrated gathers into different volumes i.e. P-impedance, S-impedance, Density and Vp/Vs using petrophysical information obtained from drilled wells. The elastic attributes of lamda-rho (λρ) and mu-rho (μρ) obtained from transformation of inversion results have been used for discrimination of "sandy" and "shaly" facies exploiting the contrast in sandstone-shale rigidity.

Introduction

The objective of this study is to understand distribution pattern of reservoir facies occurring within dominantly argillaceous sedimentary interval with the help of simultaneous inversion of 3D prestack data. The methodology adopted may facilitate firming of new well locations to further explore and exploit potential hydrocarbons in the area.

Post-stack inversion which is purely acoustic, provides information only on P-wave acoustic impedance, which is not sufficient to describe the reservoir, especially shaly reservoir. In such case pre-stack inversion estimates reservoir elastic properties in better sense.

Methodology of pre-stack inversion, also called simultaneous inversion, has been used to generate acoustic impedance (Zp), shear impedance (Zs), estimated density (ρ) and Vp/Vs volumes simultaneously. These volumes are then transformed to Lamda-rho (λρ) and Mhu-rho (μρ) volumes to infer the fluid and lithology.

Study area

The study area falls in Cambay -Tarapur tectonic block of Cambay Basin shown in figure-1, which is one of the well explored petroliferous basin of India. It has reached maturation stage in terms of exploration and exploitation. The Tertiary rift basin is filled with thick clastic deposits varying in age from Paleocene to Recent. The sedimentary column varies from volcanic-clastics to shallow marine and deltaic to fluvial deposits.

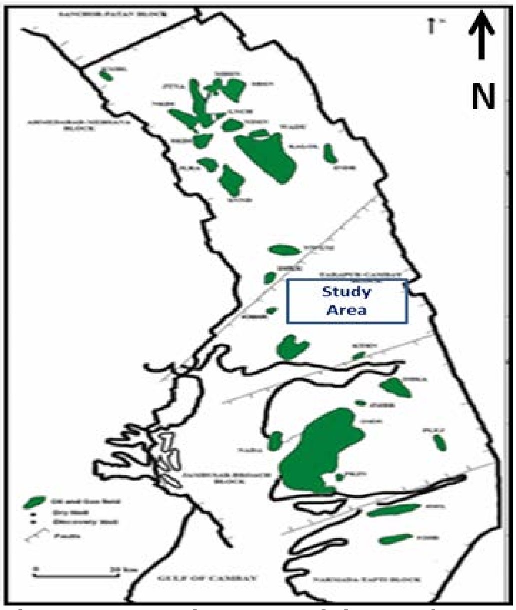

Figure 1: Location map of the study area

Fluvio-deltaic clastic sequences of Early to Mid Eocene age constitute the main reservoir facies in the basin. These reservoir units have been prolific producers of hydrocarbons since more than five decades.
In Cambay-Tarapur block, main reservoir intervals are in Eocene Pay units. Oligocene and Basal Miocene sediments also contain hydrocarbon producing reservoir intervals. Structurally, the tectonic block is characterised by a huge north-south elongated depression called Tarapur Low. A number of oil and gas fields have been discovered on intra-basinal highs and towards the eastern and western rising flanks of Tarapur Low.

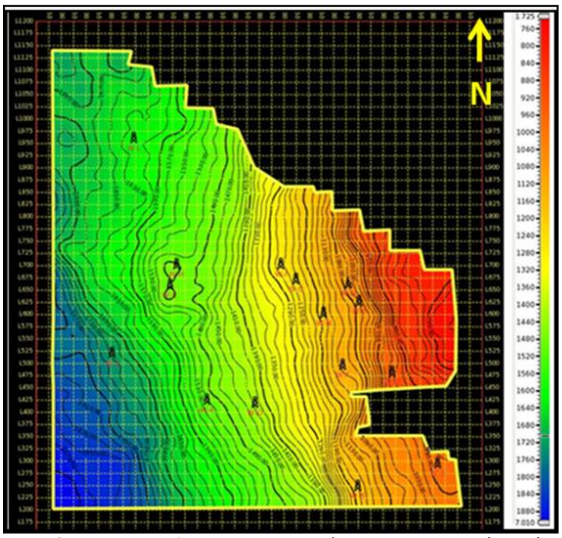

Figure 2: Time structural map at H-B level

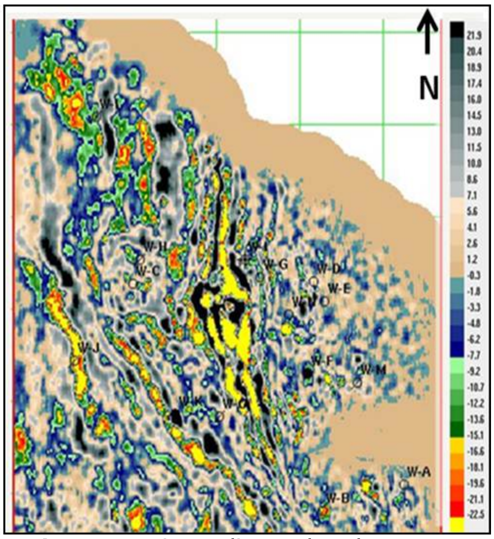

Figure 3: Time Slice at level: 1340 ms

The present area of interest is located on the eastern rise of the depression. Regional dip of the sediments is towards west (Fig.2) and is affected by north-south trending normal faults. Some of the longitudinal north-south faults are associated with roll over features. East-west trending cross faults (Fig.3) at places compartmentalizes the fault corridor and has resulted in formation of trap door prospects. Recently commercial hydrocarbon has been found in the area in Early Eocene Chhatral and Mid Eocene EP-IV stratigraphic units. EP-IV consists of fine grained sands and siltstones deposited in inter tidal environment. Chhatral unit developed within upper part of Cambay Shale Formation of Early Eocene age is deposited in shallow marine condition punctuated with lean rate of sedimentation. Chhatral unit consists dominantly shale/clay with intercalation of siltstones/silt laminae. The paper deals with characterisation of this shale rich reservoir.

Data Acquisition

The 3D seismic data was acquired during two field season 2007-8 to 2008-09 using both end on and split spread geometry with a bin size of 15*30 m. The fold was 49 and near and far offset was 42 m and 4226 m.The number of channels recorded were 1764(14*126).The data quality was of good quality
.

Data Processing

Rigorous pre-processing of the seismic data was carried for pre-stack inversion to remove as many undesirable effects as possible. Seismic transmission effects that are commonly removed or reduced in pre-inversion gather conditioning are random noise, NMO wavelet stretch, multiples and non-flat reflections as they might result in large error in inversion studies.
Data processing sequence was aimed at preserving relative amplitudes. Bad and excessively noisy traces were eliminated early in the processing sequence. Spherical divergence gain corrections and other denoise modules were applied to the data. Surface-consistent amplitude scalars generated and applied to seismic data to adjust the relative amplitude contributions of sources, receivers and offsets. As single-trace deconvolution does not maintain amplitude relationships, especially in the presence of noise, surface-consistent deconvolution was applied to resolve source, receiver and offset waveform components. Two pass surface consistent residual correction was applied to CDP gathers followed by velocity analysis at each step. Finally migration velocity analysis at close grid was performed for 3D prestack migration to get PreSTM gathers. The seismic events on PreSTM gathers were amplitude balanced, flattened and then high resolution radon de-multiple was applied to reduce incoherent noise

Simultaneous Inversion

Data Input

- PreSTM gathers transformed to angle gathers (Fig-4)
- Three seismic horizons corresponding to EP-IV, Chhatral top and Chhatral bottom named as H-A, H-B and H-C.
- The log suite consist of sonic, density, gamma, and resistivity for seven wells of which five wells had DSI logs dipole sonic (five wells) logs. Well-log editing was done to remove spikes, cycle skips and noise.
- VSP data for six wells were used for checkshot correction.
- The distribution of the wells in the study area covered by 3D seismic is shown base map (Fig-5) which shows that out of fifteen wells only three are hydrocarbon bearing and rest are dry.

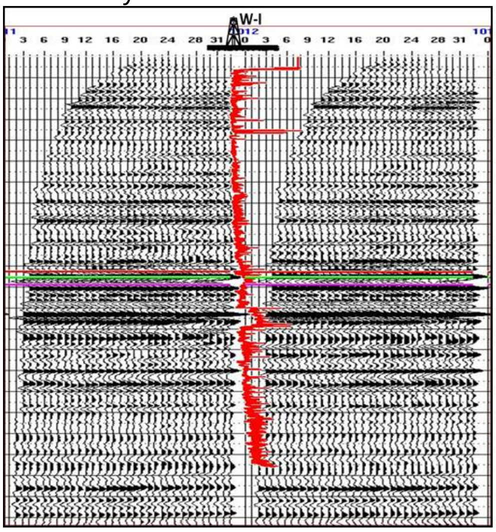

Figure 4: Conditioned PreSTM Angle Gathers

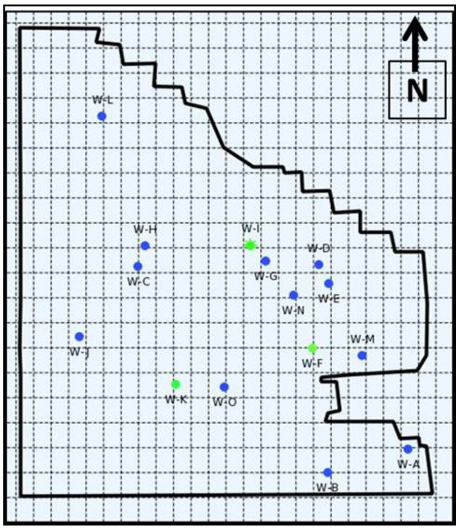

Figure 5: Base map containing wells

Well-to-seismic calibration: Sonic logs were check-shot-calibrated and synthetic seismograms were generated to create the link between rock properties and seismic data by using the convolution model of the earth's reflectivity. An optimum wavelet was determined for a well-to-seismic tie for all seven wells. The selection of wavelet is based on analysis of cross-correlation/validation between wells and inversion tests .Different wavelets were selected for each angle range. This is desirable because frequency-dependent absorption and NMO tuning will usually cause the far angle wavelets to be lower in frequency than the near angle wavelets

.

Methodology:

Initial 3D models of P-impedance (Ip), S-impedance (Is), Density and Vp/Vs were prepared using three interpreted horizons and elastic logs. These models were found to be consistent with rock model; Inversion analysis was run to determine inversion parameters in the form regression coefficients are calculated from logs.

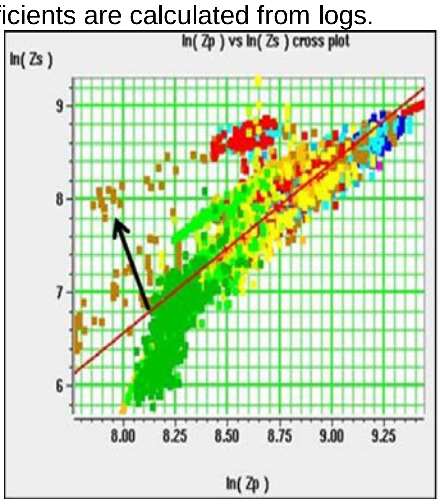

Figure 6: Cross plot Ln (Zs) Vs Ln(Zp)

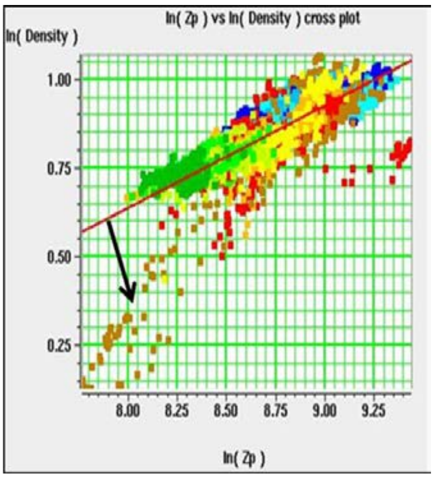

Figure 7: Cross plot Ln (Density) Vs Ln (Zp)

The **Fig-6 & Fig-7** shows plots of ln(ZS) vs ln(ZP) and ln(Density) vs ln(ZP).and it clearly indicates a roughly linear relationship between the variable . The deviations observed from these linear trends on both the cross plots shows the presence of hydrocarbon.

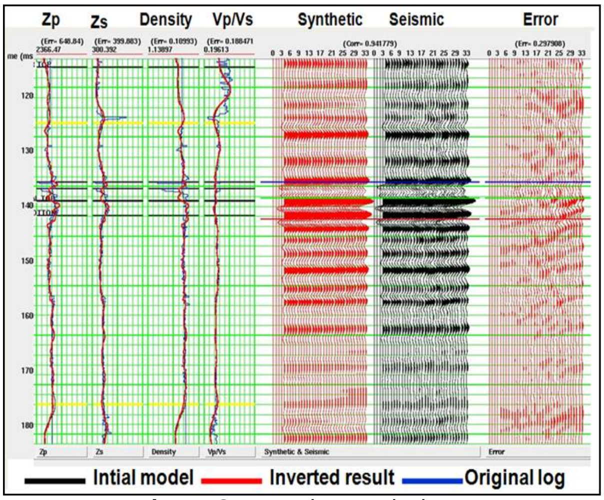

Figure 8: Inversion Analysis

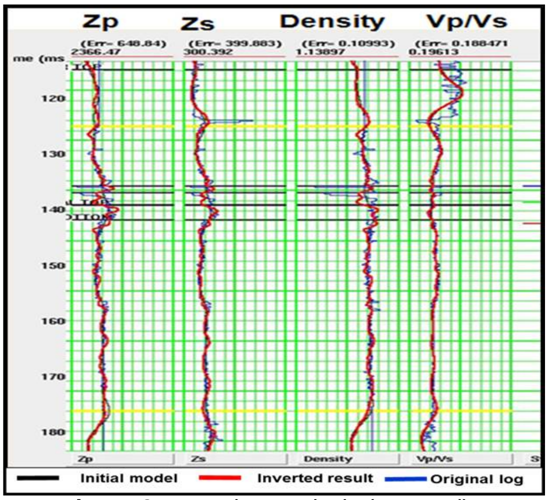

Figure 9: Inversion analysis (Zoomed)

Once the inversion parameters are fixed we go through inversion analysis to check their validity as shown in **Fig-8 & Fig-9**. , which show that there is a good correlation between inverted and original logs for P-impedance, S-impedance, Density and Vp/Vs and the error between seismic and synthetic is minimum. Once parameters were optimised, calculated parameters were used to invert PreSTM angle gathers volume into four lithological volumes in the form of P-impedance, S-impedance, Density and Vp/Vs using Hampson Russell Software. These volumes are than transformed to the elastic attributes lambda-rho (λρ) and mu-rho (μρ) to predict the lithology and fluid distribution

Results& Discussion

The study area has three successfully tested oil and gas wells out of 15 wells drilled. Well W-F is oil producer from EP-IV, well W-I is oil and gas producer from Chhatral pay and well W-K is oil producer form both EP-IV and Chhatral pays.

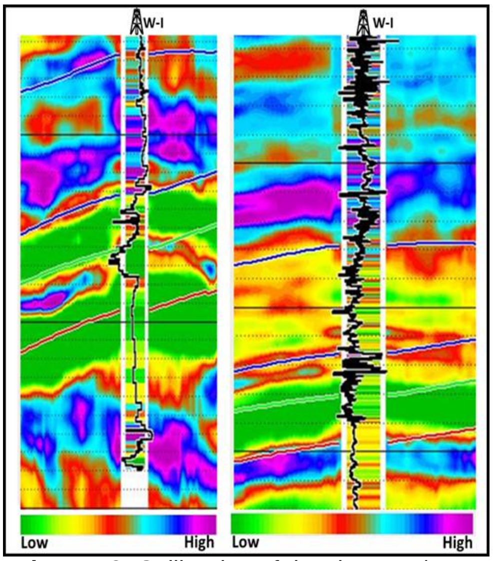

Figure 10: Calibration of density & Vp/Vs Section with synthetic logs

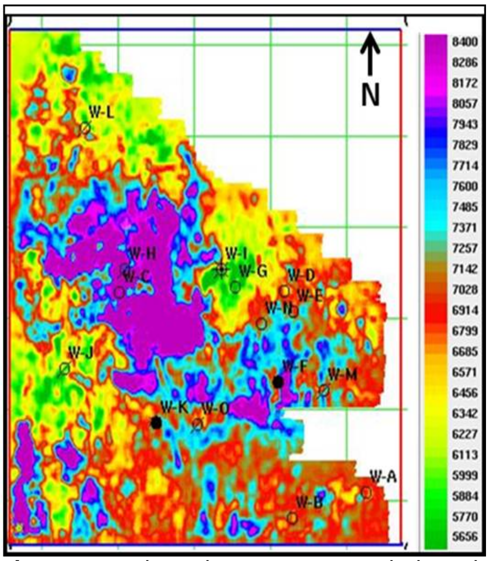

Figure 11: P-impedance: Average windowed horizon slice of (20ms i.e. 10 ms above and below H-B)

The results of inverted volumes i.e. P-impedance, density and Vp/Vs as shown in **Fig-10 & Fig-11** matches with the synthetic log at well location, Windowed based horizon slices were created from these volumes targeting Chhatral pay whose gross thickness is 30m to 40m and the effective thickness varies from 8m to 12m .Chhatral reservoirs consist of major lithological units of shale, clay intercalated with sand/slits and carbonaceous matter. These thin sand & slit units form the reservoir facies.

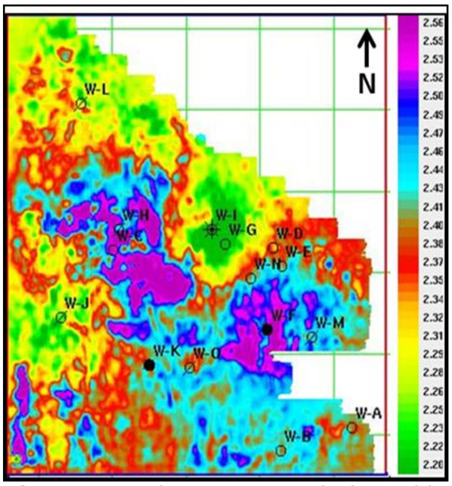

Fig 12: Density:Average windowed horizon slice (20ms i.e. 10 ms above and below H-B)

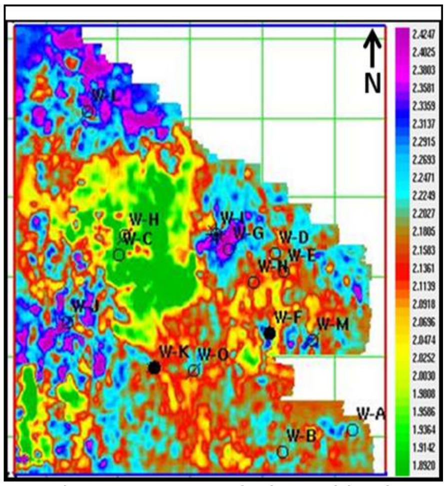

Fig 13: Vp/Vs **:**Average windowed horizon (20ms i.e. 10 ms above and below H-B)

It is observed from these slices as shown **in Fig-11**, **Fig-12** & **Fig-13** that the wells W-I & W-K encompassing Chhatral pays intervals are showing low to moderate value of impedance and density, and moderate to high Vp/Vs ratio.

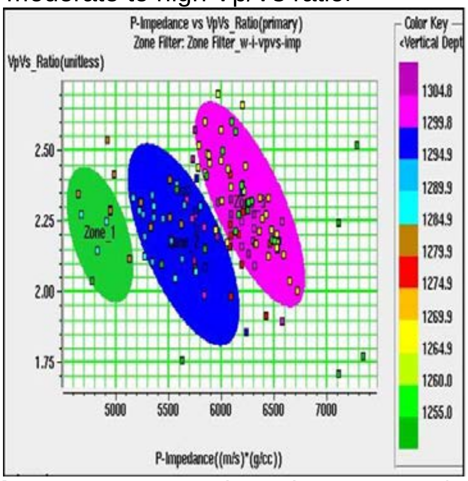

Fig 14: Crossplot P-impedance Vs Vp/Vs

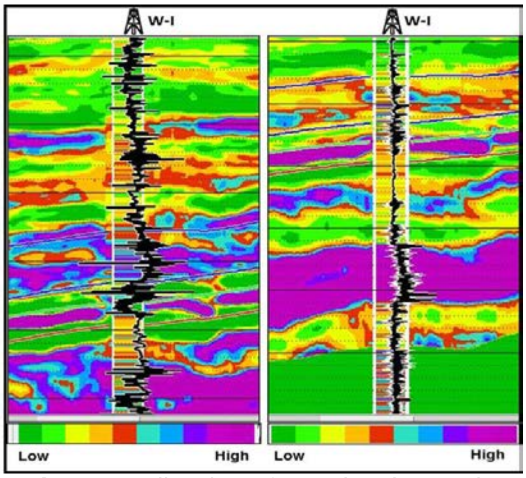

Fig 15: Calibration of Lamda-Rho & Mhu-Rho Section with synthetic logs

Cross plot between Vp/Vs and P-impedance shown **fig-14** indicate the pay zone of Chhatral consist of three types of lithologies .i e low, medium and high impedance compacted sandstone and shale.

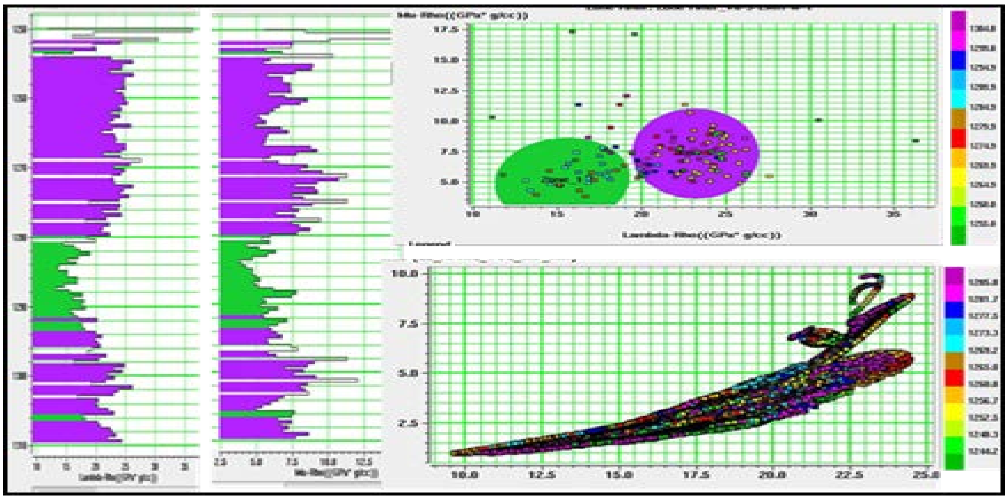

Fig 16: Lamda-Mhu Vs Mhu-Rho: Xplot/ Cross-section

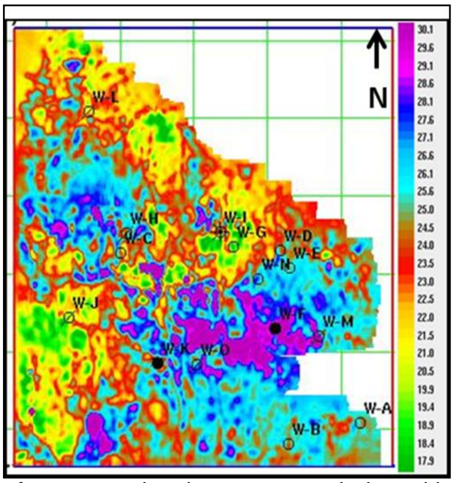

Fig 17: Lamda-Rho: Average windowed horizon slice (20ms i.e. 10 ms above and below H-B)

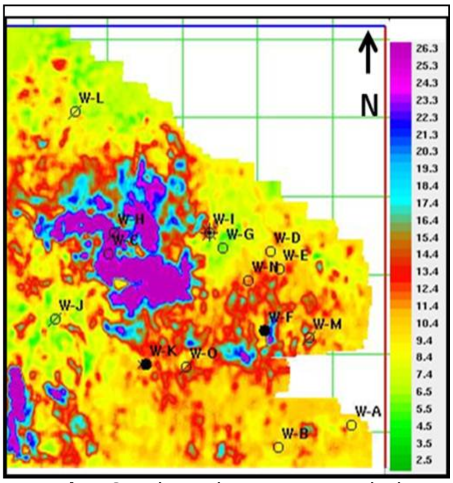

Fig 18: Mhu -Rho: Average windowed horizon slice (20ms i.e. 10 ms above and below H-B)

Lambda-Rho & Mhu-Rho Studies: The transformed lambda-rho (λρ) and mu-rho (μρ) section are calibrated at well location with synthetic Lamda-rho &Mhu-rho logs.**Fig-15** shows reasonable amount of correlation Cross plot of Lamda-rho & mhu-Rho logs as shown in **Fig-16** were taken in the reservoir interval of Chhatral pays for well W-I. The upper one is plotted from log data which infer medium value of lamda-rho and low value of mu-rho, which supports a thin band of sand and slits within producing zone .Cross plots and windowed horizon slices taken from lamda-rho & mhu-rho volume are depicted in **Fig-16**, **Fig-17** & **Fig-18**.The Mu-rho map (Fig.18) show moderate value at well locations W-I and W-K which has encountered hydrocarbon bearing reservoir facies.

Petrophysical Analysis

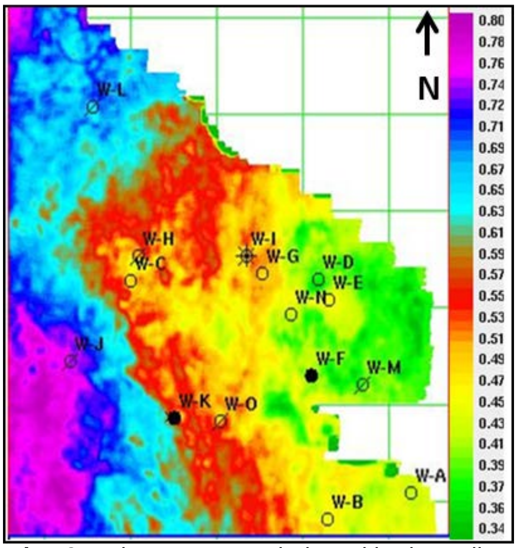

Fig 19: Vclay: Average windowed horizon slice (20ms i.e. 10 ms above and below H-B)

To validate results from inversion, suite of logs having, clay volume (VCL) was used to generate Vclay volumes through multi-attribute analysis. Further, windowed base horizon slices were generated from these volumes for the target interval of Chhatral pay. The Vclay slice suggest Vclay ranging from 45% to 55% for contributing to reservoir facies in chhatral as brought out in wells W-I, W-K, W-O (**Fig-19).**W-H has also encountered reservoir characteristics in Chhatral. Wells W-D, W-E,W-F etc. drilled in the eastern part and falling in Vclay range of 34% to 40% have encountered lesser thickness of Chhatral unit with poor reservoir facies. Wells W-L and W-J falling in Vclay range of >60% have no reservoir development in Chhatral. It suggest that Vclay map depicting intermediate percentage(45-55%) may be a good tool for discriminating reservoir and non-reservoir facies in shale dominated sequence.

Conclusion

- Results of simultaneous inversion have demonstrated that it can be used to resolve reservoir complexity especially in shale rich reservoirs.
- The case study suggest that Mhu-rho and Vclay volume provides consistent model for discrimination of reservoir facies and non- reservoir facies.
- It is found that lamda-rho is not very unambiguous fluid distributing in shaly reservoirs.

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Acknowledgement

The authors express their gratitude and sincere thanks to Ex -Director Exploration Shri Narendra Kumar Verma for motivation.

The authors express their gratitude and sincere thanks to Shri G,C Katiyar, ED-Basin Manager, Western Onshore Basin for his encouragement and permission to write this paper.
Authors are thankful to Shri Ajay Bisht, Manager (Prog.) for help to put paper in proper format.

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